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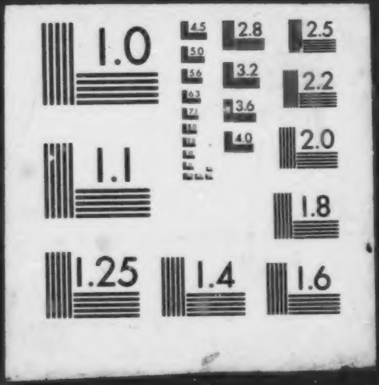
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Air Pollutant Control Techniques for Electric Arc Furnaces in the Iron and Steel Foundry Industry

GCA Corp, Bedford, Mass GCA Technology Div

Prepared for

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Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

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16. ABSTRACT

This report provides guidance for evaluating air pollutant control technologies for electric arc furnaces in the iron and steel foundry industry. It includes estimated emission factors, a discussion of emission characteristics, and lists of references resulting from an extensive literature search.

Control technologies, including equipment for evacuating emissions during melting, refining, charging, and tapping, as well as dust collection equipment, are presented. Emission data from several field tests on electric arc furnaces carried out by EPA and others are reported. Capital and annualized emission control costs for several new and retrofitted model plants are presented. The environmental impacts (estimated emissions, solid waste disposal, energy requirements, water pollution, and noise) for model plants are included.

Several regulatory options corresponding to different levels of emission control costs, energy requirements, and environmental impacts are presented.

The document outlines enforcement aspects and contains appendices with detailed field test data on existing furnaces and cost data for several model furnaces in iron and steel foundries.

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AIR POLLUTANT CONTROL TECHNIQUES FOR ELECTRIC ARC FURNACES IN THE IRON AND STEEL FOUNDRY INDUSTRY

by

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ABSTRACT

This report summarizes findings of a study to identify control technology for electric arc furnaces in the gray iron and steel foundry industry. A general description of the industry is followed by a presentation of emission rates and composition of exhaust gases. Emission control technology is discussed for melting, charging and tapping of the furnace. Several new, or novel control techniques are discussed in addition to conventional technology. Cost estimates for several control options are presented. Adverse environmental effects concern energy requirements and dust disposal and are also explored. Sampling techniques for furnace emissions are discussed, and several formats for writing an emission regulation are identified. Finally, the effect of each regulatory format on reducing furnace emissions is summarized.

CONTENTS

Abstract iii
Figures vii
Tables viii
Acknowledgment x

1.0 Introduction 1-1
  1.1 Need to Regulate Electric Arc Furnaces in Foundries . . . 1-1
  1.2 Sources and Control of Emissions. 1-1
  1.3 Regulatory Approach 1-2
2.0 Sources and Types of Emissions 2-1
  2.1 Industry Description. 2-1
  2.2 General Operations 2-1
  2.3 The Electric Arc Furnace: Operation and Emissions. . . . 2-6
  2.4 Industry Growth and Trends. 2-14
  2.5 Summary of Furnace Emission Factors 2-16
3.0 Emission Control Techniques. 3-1
  3.1 Introduction 3-1
  3.2 Evacuation of Melting and Refining Emissions. 3-1
  3.3 Evacuation of Charging Emissions. 3-9
  3.4 Collection of Tapping Emissions 3-36
  3.5 Gas Cleaning Devices 3-40
  3.6 Summary of Test Data for Particulate Emissions From Fabric Filters at Iron and Steel Foundry Electric Arc Furnaces. 3-47
  3.7 Achievable Levels of Particulate Control. 3-51
4.0 Cost Analysis 4-1
  4.1 Introduction. 4-1
  4.2 Control Costs for Furnaces Producing Iron 4-5
  4.3 Control Costs for Furnaces Producing Steel. 4-11

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CONTENTS (continued)

5.0 Environmental Impacts of Applying Control Technology. 5-1

5.1 Impact on Particulate Emissions From the Iron and Steel Foundry Industry. 5-1

5.2 Summary of Energy Requirements 5-1

5.3 Generation and Disposal of Dust Generated. 5-4

5.4 Disposal of Scrubber Wastewater and Sludge 5-10

5.5 Effect of Emission Control on Plant Noise 5-10

6.0 Compliance Test Methods and Monitoring Techniques 6-1

6.1 Measuring Particulate Emissions 6-1

6.2 Visible Emission Monitors 6-4

6.3 Visible Emissions From Foundry Roof Monitors. 6-5

7.0 Enforcement Aspects 7-1

7.1 Introduction 7-1

7.2 Concentration Limits 7-1

7.3 Mass Limits 7-2

7.4 Opacity Limits 7-3

7.5 Equipment Standards. 7-3

8.0 Regulatory Options for Control of Electric Arc Furnaces at Iron and Steel Foundries. 8-1

8.1 Summary of Control Technology Options for Iron and Steel Foundries. 8-1

8.2 Format of Regulations for the Electric Arc Furnace at Iron and Steel Foundries 8-11

8.3 Summary of Regulatory Control Options. 8-16

Appendices

A. Summary of Particulate Emissions From Fabric Filters at Gray Iron and Steel Foundry Electric Arc Furnaces. . . . A-1

B. Detailed Cost Analysis for Furnaces Producing Gray Iron Castings B-1

C. Detailed Cost Analysis for Furnaces Producing Steel Castings C-1

D. Technical Report Data D-1

FIGURES

Number		Page
2-1	Iron and steel foundry process flow and emission sources. . . .	2-4
3-1	Roof hood	3-3
3-2	Side draft hood	3-6
3-3	Direct evacuation through fourth hole	3-8
3-4	Canopy hood using building roof as part of the canopy, combined with direct furnace evacuation.	3-11
3-5	Design aspects of building evacuation system.	3-18
3-6	Sketch of furnace enclosure design at Lone Star Steel Co. . . .	3-21
3-7	Krupp furnace, sequence of events during charging	3-25
3-8	Hawley close capture hoods	3-28
3-9	The Brusa charging and preheating system.	3-34
3-10	Hooded charge bucket	3-35
3-11	Marchand design for charging emission control	3-37
3-12	Armco Steel Corporation design for tapping pit enclosure. . . .	3-39
3-13	Ladle car and ladle enclosure by Marchand	3-41
3-14	Mobile tapping hoods.	3-42
3-15	Summary of EPA test data for baghouses on EAF's producing iron	3-48
3-16	Summary of reported test data for baghouses on EAF's producing steel	3-50
4-1	Cost effectiveness of alternative control options for retrofitted iron producing furnaces (two-furnace shop)	4-10
4-2	Cost effectiveness of alternative control options for retrofitted steel producing furnaces (two-furnace shop).	4-16

TABLES

Number | | Page
2-1 Raw Materials Used for Iron and Steel Production 2-3
2-2 Chemical Analysis of Particulate Emissions from an Electric Arc Furnace 2-11
2-3 Composition of Dust Collected by Fabric Filters at an Iron Foundry 2-11
2-4 Particle-Size Distribution for Particulate Emissions From Three Electric-Arc-Furnace Installations 2-12
2-5 Summary of Emission Factors for Iron and Steel Producing Electric Arc Furnaces 2-17
3-1 Typical Exhaust Flow Rates and Particulate Removal Efficiency of Melting Control Systems. 3-5
3-2 Typical Exhaust Flow Rates and Particulate Removal Efficiency of Charging and Tapping Control Devices at Model Foundries . . 3-15
3-3 Design Data for Lone Star Steel Company Furnace Enclosure. . . . 3-22
3-4 Summary of Total Particulate Removal Efficiencies for Control Options at Iron and Steel Foundries 3-53
4-1 Engineering Parameters for Model Foundries Producing Iron and Steel 4-3
4-2 Summary of Total Annualized Control Costs for Model Existing Foundries Producing Iron Castings, in Thousands of Dollars per Year 4-6
4-3 Summary of Reported Capital Costs Compared to EPA Estimates of Total Installed Costs 4-8
4-4 Summary of Total Annualized Control Costs for Model Existing Foundries Producing Steel Castings, in Thousands of Dollars per Year 4-12
5-1 Summary of Total Particulate Emissions From Iron and Steel Foundry EAF's for Various Control Options. 5-2
5-2 Energy Requirements, in Million kWh per Year, for Melting Compared to Emission Control Options for Model Plants. 5-3
5-3 Quantity of Dust Collected at Model Foundries in Megagrams per Year 5-6

TABLES (continued)

Number | Page
5-4 Trace Metallic Components of Baghouse Hopper Dust (ppm) 5-8

8-1 Summary of Regulatory Options for a New Model 9.1 Mg/hr Furnace Producing Iron 8-17

8-2 Summary of Regulatory Options for a New Model 9.1 Mg/hr Furnace Producing Steel. 8-18

1.0 INTRODUCTION

This document concerns the control of emissions from electric arc furnaces in ferrous foundries. Emissions from production of iron and steel in electric arc furnaces in foundries are primarily particulates of respirable size. Most of the control techniques discussed herein have been used at foundries, although several newly developed techniques are also addressed.

1.1 NEED TO REGULATE ELECTRIC ARC FURNACES IN FOUNDRIES

Typically, air pollution control regulations which govern ferrous foundries require that emissions from melting of metal in the furnace be controlled. Recently, there has been interest in control of emissions generated during charging and tapping of the furnace. Nationally, annual emissions from electric arc furnaces at foundries are estimated to be 10,000 megagrams (Mg) or 11,020 short tons per year. This represents 0.8 percent of total particulate emissions from stationary sources, and is of concern since foundries are often located in populated areas or in localities where National Ambient Air Quality Standards (NAAQS) are not being attained.

1.2 SOURCES AND CONTROL OF EMISSIONS

Emissions from electric arc furnaces occur when the scrap is charged into the furnace, during melting and refining of the metal, and during tapping of molten metal. For steel furnaces, emissions also occur during backcharging; i.e., when the furnace is charged a second time, after the first charge has melted. Emissions from the electric arc furnace can be reduced to very low levels through use of proper capture devices on the furnaces and evacuation of the emissions to a gas cleaning device for collection.

Melting and refining account for about 90 percent of furnace emissions. Control technology for these emissions is well established, and currently used by most foundries. The remaining 10 percent of furnace emissions result from charging and tapping. Technology is available for effective and economical control of these operations. However, only a few foundries practice charging and tapping control; and several of the control techniques have been only recently developed, primarily for large steel-making furnaces.

1.3 REGULATORY APPROACH

In the regulatory approach, emphasis shall be put on successful capture of melting, charging and tapping emissions (i.e., good evacuation devices) at the furnace. Regulations should be written in terms of equipment specifications, especially those pertaining to the type of furnace evacuation devices. Equipment specifications would require some flexibility in a regulation to accommodate newly developed techniques and to allow selection of best control options for individual shops on a case-by-case basis, when necessary.

Regulations in terms of operating procedures; i.e., prescribing avoiding backcharging, alloying in the ladle, and carbon upgrading by means of carbon injections, etc. can also be applied. Arc furnace operators currently pay careful attention to furnace operational procedures because of the complexity of the process and for safety reasons. It is not anticipated that prescribing certain additional operating procedures to minimize emissions will adversely affect furnace operation.

A regulatory approach which specifies limits on concentration or mass of emitted particulates requires sampling of low exhaust concentrations. Such sampling is costly for small furnace operators. This approach can be substituted by opacity standards. Opacity limitations is a more convenient regulation because it is inexpensive and easy to enforce. Visual observation of the plume opacity from stack and roof monitors can ensure that dust collection devices are operated properly. Opacity standards for charging, backcharging and tapping must be judiciously applied if those fumes are unconfined. Such fumes tend to drift out of the furnace bay area, be diluted, and therefore the opacity reading is not representative of the mass emissions.

2.0 SOURCES AND TYPES OF EMISSIONS

2.1 INDUSTRY DESCRIPTION

As defined for this study, iron and steel foundries are those which produce gray, white, ductile or malleable iron* and steel castings. The differences between the types of iron and steel are chemical and physical in nature and are determined by relative concentrations of carbon, silicon, magnesium, manganese, sulfur and phosphorus. Particulate emissions are very similar for each type of iron and steel, and emissions depend mostly on furnace type and furnace charge materials.

Iron foundries pour about 85 percent of all ferrous castings in the United States while steel foundries account for the remaining 15 percent. The electric arc furnace (EAF) and raw materials for iron and steel production are very similar; consequently, furnace emissions and emission control requirements tend to be very similar for iron and steel furnaces.

2.2 FOUNDRY OPERATIONS

2.2.1 General Operations

Castings are produced in the foundry by injecting or pouring molten metal into a mold. Molds are formed by placing a pattern conforming to the external shape of the desired casting in a supporting frame. Sand is poured and compressed into the frame, around the pattern. The mold is then separated, patterns are removed, and cores are placed in appropriate locations to provide for internal cavities in the casting. Upon reassembly, the mold is ready to received molten iron from the melting furnace. Molds are formed manually in small foundries and usually by automatic machines in large foundries.

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*In this document, the term "gray iron" is used to describe all types of iron.

Raw material used for gray iron or steel castings includes: ferrous scrap metal, foundry returns, carbon and flux, fuel, refractories (furnace lining) and molding sand, as outlined in Table 2-1. Most foundries purchase scrap of a size suitable for charging directly into the furnace. Charging methods range from hand charging in small shops to mechanized bucket charging in medium-sized shops and full automatic, computerized bucket charging in new, large foundries.

At iron foundries, the charge is melted in cupola, induction or electric arc furnaces while steel foundries rely almost exclusively on the electric arc. Alloy agents are added to the furnace, after melting, or to the ladle during tapping of refined metal. After the furnace is tapped, molten metal is poured into molds by hand or at an automatic pouring station. After a cooling period, molds are separated and castings removed from mold flasks on a vibrating, impacting shakeout unit. Sand is recycled to the molding sand preparation system. Castings are further cleaned by shot-blasting and if necessary grinders to remove fins and smooth rough spots.

Malleable and ductile iron castings may be given various heat treatments including stress relieving, annealing, normalizing, quenching and tempering. Ductile iron may be given a special heat treatment. The castings are then inspected and shipped.

Figure 2-1 diagrams the process flow for a typical iron or steel foundry, Each foundry process generates certain quantities of smoke, fume and other particulate matter. Current data indicates that on the average, the furnace contributes roughly 60 percent of uncontrolled particulates emitted from foundries which melt with the EAF.[1]

TABLE 2-1. RAW MATERIALS USED FOR IRON AND STEEL PRODUCTION

Metallics

- Pig iron
- Cast iron scrap
- Steel scrap
- Turnings and borings (loose or briquettes)
- Foundry returns
- Ferroalloys
- Inoculants, including magnesium alloys

Carbon additive

- Graphite
- Electrode scrap
- Calcined gilsonite
- Anthracite
- Coke breeze

Fluxes

- Carbonates (limestone, dolomite, soda ash)
- Florides (fluorspar)
- Carbides (calcium carbide)

Fuel

Refractories

- Firebrick: alumina, silica, magnesite, graphite

Mold preparation

- Sand
- Additives, binders

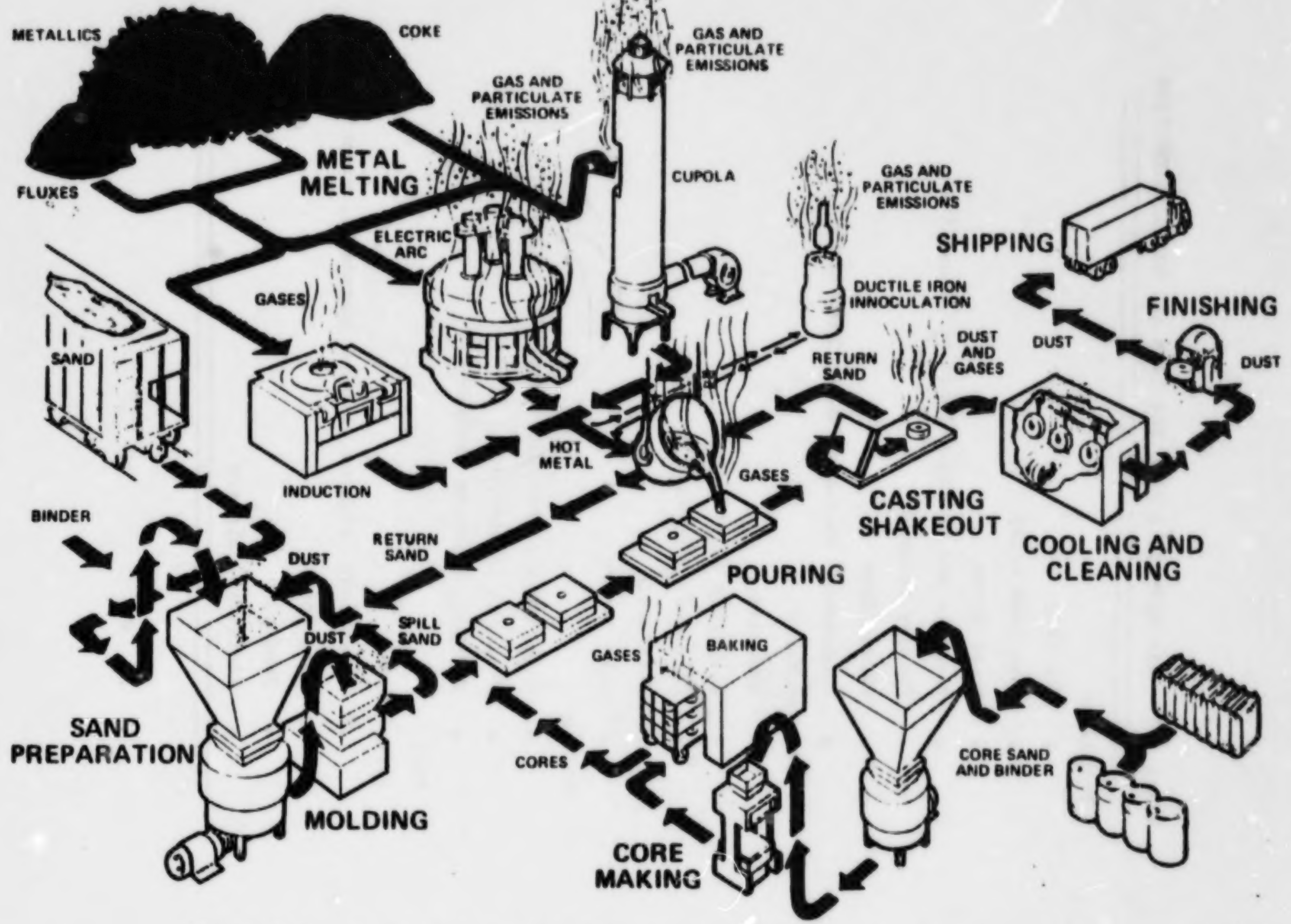
METALLICS
COKE
FLUXES
METAL MELTING
GAS AND PARTICULATE EMISSIONS
GAS AND PARTICULATE EMISSIONS
CUPOLA
GAS AND PARTICULATE EMISSIONS
ELECTRIC ARC
GASES
SAND
INDUCTION
HOT METAL
DUCTILE IRON INNOCULATION
SHIPPING
FINISHING
DUST
DUST
RETURN SAND
DUST AND GASES
GASES
CASTING SHAKEOUT
COOLING AND CLEANING
BINDER
DUST
RETURN SAND
POURING
DUST
SPILL SAND
GASES
BAKING
SAND PREPARATION
MOLDING
CORES
CORE MAKING
CORE SAND AND BINDER

Figure 2-1. Iron and steel foundry process flow and emission sources.

2.2.2 Furnaces Used in Iron and Steel Foundries

About 70 percent of all iron is produced in the cupola, which is a vertical, refractory lined, cylindrical steel shell charged at the top with layers of metal, coke and flux materials. Compared to other furnace types, cupolas produce significantly greater quantities of gaseous (carbon monoxide) and particulate emissions because air is blown through the cupola to support combustion of coke as a source of heat. Emission controls are usually more expensive and precise control of metallurgy is difficult with cupolas; nevertheless, cupolas are likely to remain prominent in iron foundries because they handle any type of scrap and their energy consumption is often lower than arc furnaces. However, cupolas are rarelv used in steel foundries today.

Coreless induction furnaces are typically small in size and melt iron or steel through heat generated by a changing electrical flux created by an induction coil placed around the furnace shell. Unlike the situation with cupolas and electric arc furnaces, the furnace charge for an induction furnace must be free from oil and water to avoid explosions. To avoid these problems, the scrap charge to an induction furnace is often dried, cleaned and/or preheated. Emissions from induction furnaces are considerably less than cupolas or arc furnaces except during charging. Channel induction furnaces are often used to hold and superheat molten iron received from the primary melting furnace, and operation commonly termed "duplexing."

Reverberatory furnaces are primarily used in malleable iron foundries to receive and hold molten iron from a cupola and some open hearths which are still used in steel operations. Fired by oil, coal or gas, these large capacity furnaces provide additional refining and superheating prior to pouring. A second type of reverberatory furnace is small in size and used for melting.

Capacities are less than 2 tons, and emission levels are low, which makes the furnace popular for small foundries.

The electric arc furnace is the primary melting furnace used at steel foundries. It is also widely used at iron foundries, although not as extensively as the cupola furnace. A more detailed discussion on the EAF and its operation is provided below.

2.3 THE ELECTRIC ARC FURNACE: OPERATION AND EMISSIONS

The electric arc furnace (EAF) is a refractory lined, cylindrical vessel constructed of heavy, welded steel plates. Three graphite electrodes mounted overhead can be raised and lowered into the furnace through water cooled holes in the roof. With electrodes in the raised position, the furnace roof can be swung aside to allow for charging. Top charging is most prevalent since it can be accomplished quickly, although some small or older furnaces are charged through side doors. Overhead cranes are used to transfer material within the foundry and to charge the furnace. Chemical agents, as required, are added with the scrap charge, at a later time through side or slag doors, or to the ladle during tapping. Alloy addition to the ladle increases availability of the furnace and can increase overall production. The entire furnace can be tilted to facilitate slag removal and tapping of the hot metal. After melting, molten iron is poured into a ladle or a holding furnace and then cast into molds.

Electric arc furnaces for steel foundries are very similar to those used for iron. At foundries which pour both iron and steel, both metals can be produced in the same furnace. Steel production often uses an oxygen lance to dislodge scrap which adheres to furnace walls, to adjust the furnace chemistry or to increase the melt rate. Steel furnaces are often backcharged with additional scrap during the melt period. The oxygen lance and backcharging temporarily increase emission rates from steel furnaces. Iron production does not ordinarily use these operations. The chemical composition of emissions from iron and steel production for the most part is very similar except for some differences in relative amounts of certain metal oxides.

Compared with other types of furnaces, the EAF offers several advantages. An induction furnace requires a clean charge, but an arc furnace can melt dirty or oily scrap provided the furnace is charged in a manner which avoids localized high concentrations of combustibles. However, excessive oil may cause premature deterioration of the furnace roof and fume collectors in addition to substantially increasing emissions. Electricity consumption is lower for an arc furnace compared with an induction furnace. Advantages of the arc furnace over the cupola include: better control of melt chemistry, and sometimes lower costs for emission control equipment, and relative ease of intermittent operation.

2.3.1 Charging

Iron and steel scrap is loaded into a charge bucket with an overhead crane, and the filled bucket is weighed on a scale. Typical charge composition for gray iron is:[2,3,4]

- 50 to 60 percent iron (approximately 80 percent foundry returns and 20 percent cast iron turnings or borings).
- 37 to 45 percent steel (approximately 70 to 100 percent steel pieces and 0 to 30 percent steel turnings).
- 0.5 to 1.1 percent silicon (usually as ferro silicon).
- 1.3 to 1.7 percent carbon raiser.

Foundry returns include sprues, end gates, risers (scrap pieces from a casting), defective castings, and borings from machining operations. In some cases, pig iron may be included with the scrap. Carbon raiser is in the form of pure carbon (graphite) or coke breeze.

Charge composition for steel production differs from iron production in that the foundry returns are mostly steel, and no carbon raiser is added to the charge. In producing steel, the carbon level is substantially reduced, about 6 to 7 times lower than for iron production.

Charging a hot electric arc furnace produces emissions from:

- vaporization and partial combustion of oil introduced with any borings, turnings, and chips.
- oxidation of organic and other foreign matter which may adhere to the scrap.
- liberation of sand particles which are introduced into the furnace on the surface of casting returns.

Charging emissions consist of particulates, carbon monoxide, hydrocarbon vapors, and soot, and are typically vented to the atmosphere through monitors or vents in the foundry roof. Charging with dirty, oily scrap causes heavy emissions of fume, hydrocarbon and other vapors while a clean charge substantially reduces fume generation. The magnitude of charging emissions has not been extensively measured as such emissions are often unconfined and difficult to segregate from other foundry emission sources. Extrapolation of limited emission test data from charging and tapping at steel-making EAF's[5] indicates that charging and tapping at iron and steel foundries account for 10 percent of total furnace emissions, when alloying is conducted in the ladle. When there are no alloys added to the ladle, as sometimes the case with iron production, then charging and tapping are estimated to produce 5 percent of total furnace emissions.

A steel furnace is sometimes backcharged with additional scrap once the initial charge has melted. Backcharging causes a violent eruption of iron oxide fume with a strong thermal driving force. Particulates and significant quantities of carbon monoxide are evolved during backcharging; however, no quantitative data regarding particulate emissions during backcharging are available.

2.3.2 Melting and Refining

After charging, the furnace roof is replaced and electrodes slowly lowered into the charge while applying electrical power. Melting is accomplished by heat generated from electrical arcing between the electrodes and the charge. As electrodes bore into the solid charge, much fume and noise results. Automatic controls maintain the desired current by activating motors which raise or lower electrodes. A demand limiter device is often used to automatically control power which is delivered to the electrodes through a transformer. When electricity consumption in the foundry exceeds a preset limit, a cycle of raising the electrodes, reducing transformer output, and lowering electrodes is initiated. Termed a "shed," this operation generally causes a momentary increase in furnace emissions. During melting and refining, electrodes lose 4 to 6 kilograms of their weight per megagram of iron produced, which results in carbon monoxide emissions.[6]

After the charge is melted, the molten bath is manually skimmed to remove impurities which have collected in the slag. The furnace is tilted about 15 degrees from the vertical, and slag is withdrawn into a slag pit. After slagging, power is restored for 15 to 30 minutes to further refine and superheat the melt, and the iron chemistry and bath temperature are checked and adjusted as necessary.

During melting and slagging, emissions consist mainly of:

- particulates as metallic and mineral oxides generated from vaporization of iron and transformation of mineral additives.
- carbon monoxide from combustion losses of the graphite electrodes, carbon raisers and carbon in the metal.
- hydrocarbons from vaporization and partial combustion of oil remaining in the charge.

During melting, fumes escape from the furnace through electrode annuli (holes), slag doors, the roof ring (the joint between the furnace shell and roof) and sometimes the tap spout. Proper maintenance of the furnace will minimize escape of fume through these openings, and improve the efficiency of fume evacuation systems used for control of melting emissions.

The rate of emissions from iron EAF's during melting and refining varies substantially with quality and cleanliness of scrap, and is dependent to a lesser degree on charge composition, melting rate and tapping temperature. While the literature reports emission rates ranging from 2 to 20 kilograms of particulate per megagram of iron charged (4 to 40 pounds per ton) a study conducted for EPA concluded that on the average, emissions are 7.0 kg/Mg (14 lb/ton).[6] The dependency of emission rate on charge quality was demonstrated by source tests which showed that emissions increased by up to 100 percent when dirty substandard scrap was substituted for clean scrap in an electric arc furnace.[7]

The composition of particulate emissions from iron EAF's during melting and refining was determined for three iron foundries, as shown in Table 2-2.[8] Iron oxide and silicon dioxide were the main components, while trace amounts of several other metal oxides were also present. Analysis of dust collected by a fabric filter at a fourth iron foundry EAF is shown in Table 2-3.

Table 2-2. CHEMICAL ANALYSIS OF PARTICULATE EMISSIONS FROM AN ELECTRIC ARC FURNACE[8]

Constituent	Proportion of total particulate, weight percent		
	Foundry A	Foundry B	Foundry C
Iron oxide	75-85	74-85	75-85
Silicon dioxide	10	10	10
Magnesium oxide	2	0.8	1
Manganese oxide	2	2	2
Lead oxide	1	2	0.5
Alumina	0.5	1	0.5
Calcium oxide	0.3	0.2	0.8
Zinc oxide	0.2	2	0.3
Copper oxide	0.04	0.03	0.01
Lithium oxide	0.03	0.03	0.03
Tin oxide	0.03	0.3	0.02
Nickel oxide	0.02	0.03	0.01
Chromium oxide	0.02	0.07	0.01
Barium oxide	0.02	0.07	0.01

Table 2-3. COMPOSITION OF DUST COLLECTED BY FABRIC FILTERS AT AN IRON FOUNDRY[9]

Constituent	Weight percent
Ferrous oxide - FeO	8.75
Ferric oxide - Fe_2O_3	41.2
Silicon dioxide SiO_2	34.9
Magnesium oxide - MgO	5.0
Aluminum oxide - MgO	4.7
Manganese dioxide - MnO_2	8.0
Calcium oxide - CaO	1.4

This analysis indicates substantial amounts of oxides of manganese, aluminum and magnesium in addition to iron and silicon. Particulates generated during melting and refining have very small median diameters; data presented in Table 2-4 shows that 80 percent of the dust is smaller than 5 microns.[9]

Table 2-4. PARTICLE-SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM THREE ELECTRIC-ARC-FURNACE INSTALLATIONS[9]

Particle size, micrometers	Cumulative percent by weight for indicated particle diameter		
	Foundry A	Foundry B	Foundry C
Less than 1	5	8	18
Less than 2	15	54	61
Less than 5	28	80	84
Less than 10	41	89	91
Less than 15	55	93	94
Less than 20	68	96	96
Less than 50	98	99	99

While emissions from steel-producing furnaces are similar to those from iron melting, there are some differences. The oxygen lance, when used, temporarily produces a large gas volume, increased particulate emissions and substantial amounts of carbon monoxide. Carbon monoxide from lancing is typically combusted at the furnace by air drawn through furnace openings, or by mixing furnace exhaust gases with outside air. Unlike iron furnaces, steel furnaces are often backcharged which results in a violent eruption of iron oxide fume. Melting and refining emissions from steel furnaces average about 8.0 kg/Mg of steel (16 lb/ton).[10] Peak emission rates which occur during oxygen lancing and backcharging are two or three times larger than the average.

2.3.3 Tapping

When the proper chemistry and metallurgy are reached, the melt is tapped at a temperature of about 1,500°C (2730°F) for iron and 1600°C (2910°F) for steel. The electrodes are raised, the furnace tilts up to 45 degrees, and refined metal flows into a ladle. The melt is then poured into molds, or temporarily stored in the molten state in holding furnaces. During tapping, sparks and fumes consisting of molten iron or steel are generated in abundant quantities and become a source of ferrous oxide particulate emissions. Tapping of iron generally produces considerably less fume than the charging of the furnace. However, when alloys are added to the ladle, tapping emissions are somewhat increased. Tapping of steel furnaces typically generates fumes at a rate somewhat greater than charging, and considerably greater than tapping of iron. Higher emission rates from tapping of steel furnaces are due to the higher temperature of steel production and the fact that more alloys are generally added to steel, compared to iron. Tapping emissions are often unconfined and escape as fugitive emissions through foundry roof vents.

2.3.4 Furnace Yields

The yield of the arc furnace is high, as 94 to 98 percent of the charge is recovered as iron. About 0.70 percent of the charge escapes as particulate emissions while the remainder is lost to the slag. Yields for steel foundries are in the order of 92 to 94 percent.[9]

2.3.5 Energy Considerations

The EAF consumes 450 to 625 kilowatt hours (kWh) per ton of iron melted, and 410 to 570 kWh for steel, depending on the bath temperature and quantity of borings in the charge.[9] The lower figure is based on a charge containing 10 percent borings while the higher consumption relates to a charge with over 50 percent uncompressed, oxidized borings. Borings are seldom used in steel production. In the case of steel production, power consumption is a function of the bath temperature, amount of oxygen applied, and type of steel being produced.

2.4 INDUSTRY GROWTH AND TRENDS

Production of ferrous casting is largely influenced by the general economic climate and consequently, shipments from iron foundries decreased from 18.1 million short tons in 1973 to 15.3 million tons in 1976. Shipments of steel castings dropped slightly from 1.89 million tons in 1973 to 1.80 million tons for 1976. However, production of ferrous castings in 1976 was substantially improved over 1975 due to an easing of material shortages, increased demand by the automobile industry and general improvement of the economy. Future demand for ferrous castings is considered to be strong. Foundrymen anticipate an increase in iron production of 25 percent by 1981, accompanied by a 30 percent increase in steel castings.[11] Recent projections by the Department of Commerce are more optimistic, suggesting that annual demand for iron castings will reach 24 million tons by 1985, a substantial 75 percent increase over 1976.[12] The projected demand will be met by existing, unused capacity and by construction of new facilities. Only 73 percent of available capacity was used in 1976, and current plans for new equipment will increase foundry capacity by 18 percent in 1981.[11] It is anticipated that major expenses for air pollution control at existing foundries will soon peak, thus freeing capital for equipment purchases. Of the 10 billion dollars expected to be spent by the metal casting industry by 1986, 1.2 billion is budgeted to meet current and anticipated environmental regulations. Although demand for castings is subject to cyclical swings, iron is expected to account for a majority (85 percent) of ferrous metal castings in the future.

New installations of electric arc furnaces at foundries have increased steadily over the years. The American Foundrymen's Society has indicated that the melting capacity of arc furnaces was 3.5 million tons/yr in 1974 and will likely increase to 5.0 million tons by 1980.[13] At a typical operating time of 4000 hours per year and an average furnace production of 9.1 Mg/hr (10 tons/hr), about seven new arc furnaces per year would be required to meet these projections.

Steel foundries use the electric arc furnace almost exclusively, although there are a few open hearth furnaces operating at older foundries. There are about 350 electric arc and about 25 open hearth furnaces operating at steel foundries in the country.

For new installations, arc furnaces are somewhat more common than the traditional cupola because of improved metallurgical control, reliable energy sources and relative ease of air pollution control. However, escalating electricity costs coupled with improvements in the design and operation of the cupola suggests that a significant percentage of iron will continue to be melted in this type of furnace. When high production rates are required, the cupola is generally preferred over an electric furnace. Induction furnace installations are also expected to continue to increase substantially in number because of their operating flexibility and low rate of emissions. One estimate suggests that 80 furnaces per year will be built with a combined total capacity of about 340 Mg/hr (370 tons/hr) each year.[14] Reverberatory furnaces are not expected to become more prominent since they require substantial amounts of fossil fuel.

Presently, about 60 percent of all ferrous castings are poured by independent jobbing foundries, for sale to others. These foundries tend to be small and generally pour a variety of speciality castings and alloys. The remaining 40 percent of ferrous foundries are the "captive" shops which produce castings for use by the parent company.

2.5 SUMMARY OF FURNACE EMISSION FACTORS

Emissions from iron furnaces during melting and refining have been documented to range from 2 to 20 kg particulate per megagram of iron charged to the furnace (4 to 40 lbs/ton), with an average value of 7.0 kg/Mg (14 lb/ton) charged.[6] Average emission rates from steel furnaces have been reported at 8.0 kg/Mg charged (16 lb/ton), but the range of values is unavailable.[10]

Emission factors for charging and tapping at foundries have not been documented to date. Fumes generated by charging and tapping are ordinarily uncollected at foundries, and it is therefore difficult to quantitatively measure emission rates. However, extrapolation of limited emission test data from EAF's in the steel-making industry[5] has provided the following best available estimates for foundry EAF's. Charging and tapping together are estimated to account for 10 percent of total uncontrolled emissions from both iron and steel producing EAF's, when alloying is conducted in the ladle. When there is no alloying in the ladle, charging and tapping produce about 5 percent of total furnace emissions. Tapping emissions are normally greater at steel foundries because of the greater amount of alloys added to the ladle during tapping, and the somewhat greater temperature of molten steel (by about 200°F or 90°C) as compared to iron production. Based on these data, Table 2-5 lists emission factors which will be used in the cost analysis, Section 4 of this report.

TABLE 2-5. SUMMARY OF EMISSION FACTORS FOR IRON AND STEEL PRODUCING ELECTRIC ARC FURNACES

	Uncontrolled emissions, kg/Mg	
	Iron furnaces	Steel furnaces
Melt and refine	7.0	8.0
Charge and tap	0.7*	0.8

*With alloys added to the ladle.

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3.0 EMISSION CONTROL TECHNIQUES

3.1 INTRODUCTION

Control of emissions from the electric arc furnace (EAF) requires two separate steps:

- Evacuation or containment of fumes
- Removal of particulates from the evacuated exhaust gas.

This section discusses emission control techniques in common use and also discusses control techniques which may be widely used in the near future. Control of fumes from the melting phase of furnace operation is straightforward, and currently practiced at most foundries. Control of fumes from charging and tapping is not widely practiced at existing foundries. Recently, new designs for control of charging and tapping have been installed on several EAF's and appear promising for economical fume control. In addition, several conceptual designs for charging and tapping control have been developed, and are also addressed in this chapter.

3.2 EVACUATION OF MELTING AND REFINING EMISSIONS

Virtually all EAF's in iron and steel foundries collect furnace emissions during melting and refining with one of three basic systems:

- Roof hoods
- Side draft hoods
- Direct furnace evacuation

Selecting the best system for an EAF depends on physical and structural constraints at the foundry and metallurgical requirements of the furnace.

When properly designed and maintained, each system can provide efficient capture of melting emissions and direct them to a gas cleaning device (usually a fabric filter). However, there is normally a small leakage of fume from the furnace or furnace evacuation systems. Some fume inevitably escapes through electrode holes, improperly sealed roof rings and slag doors, especially during initial meltdown and oxygen lancing, if used.

Melting contol systems are not designed to collect emissions from charging and tapping. The collection hoods or ducts are attached to the furnace roof and become inoperative during charging (when the roof is removed) and tapping (when the furnace tilts and disconnects from the main exhaust duct). This section discusses basic control equipment for melting and refining emissions with the understanding that variations of each system are often encountered in the field. Later sections within this chapter address control technology for charging and tapping.

3.2.1 Roof Hoods

The roof hood is attached directly to the EAF, completely enclosing the furnace top as illustrated in Figure 3-1. Extensions of the hood may also collect fumes from the pouring spout, and slag or working door. Hood suction maintains a slight draft through electrode holes and through small gaps between the roof ring and furnace top, effectively drawing fumes into the hood. A disadvantage of roof hoods is that access to electrodes and water cooling glands is restricted, making maintenance and repairs more difficult. This problem is partially eliminated by providing access doors on the hood assembly. The full roof hood is the heaviest of the furnace evacuation systems. When retrofitting an EAF, allowances must be made for increased structural loads

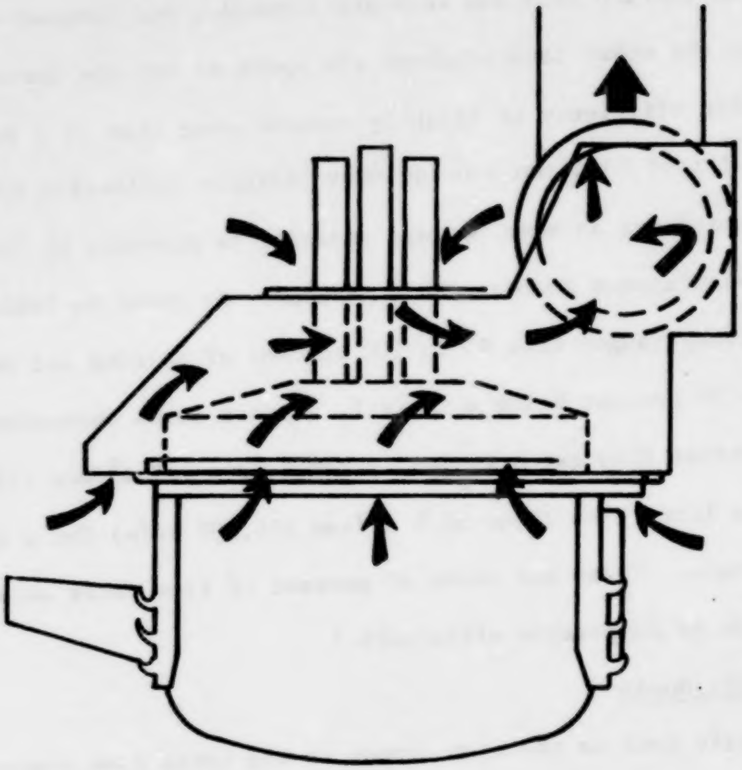

Figure 3-1. Roof hood

on both the furnace roof, base and the mechanisms which remove the roof for charging.

A modification of the roof hood design, called a two-section hood, reduces access and weight problems which may be associated with the full roof hood. This two-section hood has separate subhoods, one located over the electrodes and the other located above the space around the furnace roof gap. Collection efficiency is slightly reduced over that of a full roof hood. The full roof hood can provide most reliable collection of melting and refining emissions as some storage capacity is provided by the hood to contain an instantaneous increase in emissions. As shown in Table 3-1, control efficiency ranges from 95 to 100 percent of melting and refining emissions with 99 percent being a typical, maximum level encountered at foundries. Exhaust flow rates typically range from 7.7 m^3/sec (16,000 acfm) for a 3.9 Mg/hr furnace to about 30.0 m^3/sec (64,000 acfm) for a large, 22.7 Mg/hr furnace. These are about 60 percent of flow rates encountered by side draft hoods of comparable efficiency.[1]

3.2.2 Side Draft Hoods

The side draft hood is the most common of the three fume evacuation systems. It is also mounted on or near the furnace roof as illustrated in Figure 3-2. The hood is designed with one side open for the electrodes so their travel is not restricted. As fumes escape from electrode holes they are drawn into the open side of the hood. Vanes for directing air flow are provided on the ends of the finger ducts. Hoods may also be installed over the pouring spout and slag door to capture fumes which may escape during melting. Larger exhaust volumes are required for side draft as compared to the roof hood since enough suction must be maintained to draw fumes laterally

TABLE 3-1. TYPICAL EXHAUST FLOW RATES AND PARTICULATE REMOVAL EFFICIENCY OF MELTING CONTROL SYSTEMS*

	Typical exhaust flow rate for model furnaces in m^3/sec			Particulate removal efficiency	
	Furnace size			Range	Typical maximum
	3.9 Mg/hr	9.1 Mg/hr	22.7 Mg/hr		
Side draft hood	12.9	19.8	50.00	90-100	99
Roof hood	7.7	11.9	30.0	95-100	99
Direct evacuation	3.2	5.0	12.5	90-100	99

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*Data source: Reference 1.

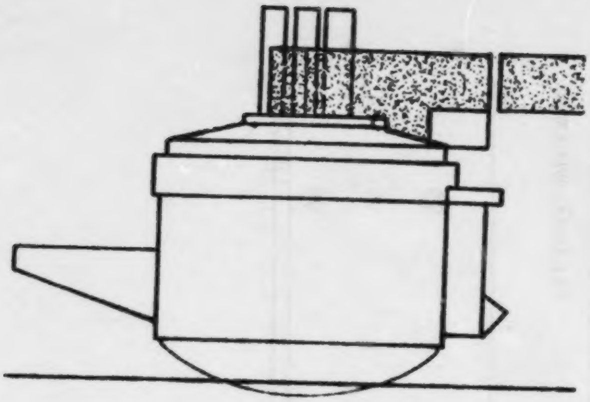


Figure 3-2. Side Draft Hood

into the hood. The larger exhaust flow insures combustion of carbon monoxide and reduces downstream exhaust temperatures. The side draft hood is simpler than a roof hood, places less weight on the furnace and furnace tilting mechanism, and improves access for maintenance of electrodes and cooling glands. To insure effective capture of melting emissions, the furnace roof must be sealed tightly to avoid the escape of fume. This is not a requirement of roof hoods which enclose the entire furnace top.

Retrofitting an existing furnace with a side draft hood generally presents few problems. However, one large, new foundry reported severe deterioration of the finger-like projections which collect fumes from electrode ports. The furnace was directly evacuated, with the side hood designed to catch fugitive emissions from the electrodes. Heavy stainless ductwork was eroded in a matter of weeks, and after many attempts at solving the problem, the company installed a roof hood.[2] However, this is not considered a common problem as many side draft hoods are operating quite satisfactorily on EAF's of all sizes.

Side draft hoods have the greatest exhaust flow rate of the three devices for control of melting and refining emissions. Flow rates range from about 12.9 m^3/sec (27,000 acfm) for a 3.9 Mg/hr furnace to about 50 m^3/sec (106,000 acfm) for the large, 22.7 Mg/hr furnace. These flow rates are typical of nearly recent installations; older, less efficient side draft hoods used lower flows. The maximum collection efficiency expected from a side draft hood is 99 percent, ranging from 90 to about 100.[1]

3.2.3 Direct Furnace Evacuation

Direct evacuation is accomplished through a fourth hole (sometimes termed a "snorkel") in the furnace roof or sidewall, as illustrated in Figure 3-3. A slight negative pressure in the furnace is maintained by a damper in the exhaust duct, which is often automatically controlled by pressure sensors. Furnace fumes are withdrawn through an elbow which is water cooled or refractory lined. Direct evacuation is the most effective method for collecting melting emissions and also results in the lowest exhaust volume. Unlike roof and side draft hoods, direct evacuation requires greater cooling of exhaust gases before entering the gas cleaning device. Cooling is usually accomplished by introducing dilution air, although atomizing water spray chambers, radiant-convection coolers, and air or water cooled duct work may also be used. When exhaust volume is minimized, the gas cleaning device can be of a smaller size and both capital and operating costs are reduced.

While direct evacuation is the most efficient method for collecting melting emissions, it cannot be applied to all EAF's because the internal furnace atmosphere is affected, which in turn influences the chemistry of the melt. The slight, but constant influx of outside air to the furnace cools the slag, makes temperature control difficult and oxidizes carbon in the bath to form

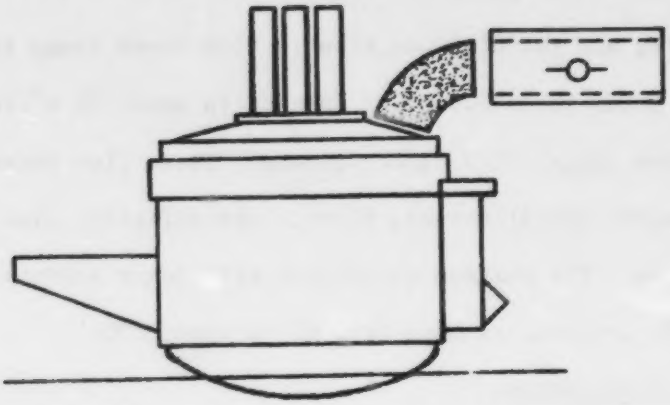


Figure 3-3. Direct Evacuation Through Fourth Hole

carbon monoxide. As a result, direct evacuation systems are least applicable to EAF's which pour high carbon alloys and certain other specialty iron and steel. Direct evacuation is more common with steel making EAF's than with foundry furnaces. It is rarely used, if at all, with iron foundry EAF's.

Formation of excessive carbon monoxide, which can occur with direct evacuation systems, also causes some potential for explosions downstream in the exhaust duct work. This potential problem is usually eliminated by leaving gaps between the furnace and fourth-hole elbow or between the elbow and exhaust duct. This allows introduction of outside air to the exhaust. Because of prevailing high temperatures and excess air, carbon monoxide is readily oxidized to carbon dioxide. Inflow of air also cools the exhaust, reducing deterioration problems in downstream duct work from high temperatures.

Direct evacuation is generally not applicable to iron-producing EAF's because the inflow of fresh air to the furnace causes excessive oxidation of carbon, and it is difficult to maintain adequate carbon in the melt. On small steel furnaces, direct evacuation is not always a viable option because of (1) lack of space for fourth hole in furnace roof and (2) pressure fluctuations in furnace, which are too rapid for automatic control of dampers in the exhaust duct.

The direct evacuation system is probably the device most easily retrofitted to an existing furnace. However, problems reported concerning some EAF's which were retrofitted with direct evacuation include: additional weight on the furnace roof, excessive deterioration of shell refractories and roofs, water cooling problems and clearance problems with roof rotation for charging.

Typically, exhaust flow rates for direct evacuation are 25 percent of those required for comparable fume control with side draft hoods. Table 3-1 shows flow rates ranging from 3.2 m^3/sec (7,000 acfm) for the 3.9 Mg/hr furnace to about 12.5 m^3/sec (26,000 acfm) for the large 22.7 Mg/hr furnace. Because the exhaust gas temperature is considerably greater with direct evacuation systems, compared to side draft hoods, substantial dilution air is normally introduced to cool gases prior to the gas cleaning device (baghouse). Particulate removal efficiency is comparable to side draft hoods, ranging from 90 to 100 percent, with a typical maximum level of 99 percent for well-designed systems.

3.3 EVACUATION OF CHARGING EMISSIONS

EAF's are normally charged by removing the entire roof-electrode-fume hood assembly and dropping scrap into the furnace with drop-bottom charging buckets. As scrap contacts the hot furnace, fumes consisting of hydrocarbon vapors and soot (from entrained oil), iron oxides (from splashing and oxidation of iron), and smoke (from dirt on the scrap) are generated. Charging emissions have traditionally been vented to the atmosphere through roof monitors, since conventional fume collection devices only collect melting emissions. However, because charging and tapping often result in substantial visible emissions, it is becoming more common for regulatory agencies to require control of charging and/or tapping operations.

There are four basic techniques applicable for collecting charging emissions:

- Canopy hoods
- Building evacuation
- Furnace enclosures
- Specially designed, "close capture" hoods

Each technique also applies to control of tapping emissions, which is discussed in Section 3.4. Additional techniques are available for control of charging emissions. For example, charging emissions can be reduced by use of clean scrap. Although most foundries currently seek high quality scrap, dirty scrap can be cleaned prior to charging by preheaters or a degreasing process. Conceptual designs for collecting charging emissions include the hooded charge bucket and closed charging systems, althogh these are not in use at domestic foundries.

3.3.1 Canopy Hoods

The canopy hood is the most common device in current use for collecting charging and tapping emissions at foundries. Located above the overhead crane, canopies are normally operated only during charging and tapping, when the melting collection system is inoperative. A typical canopy hood collector is illustrated in Figure 3-4.

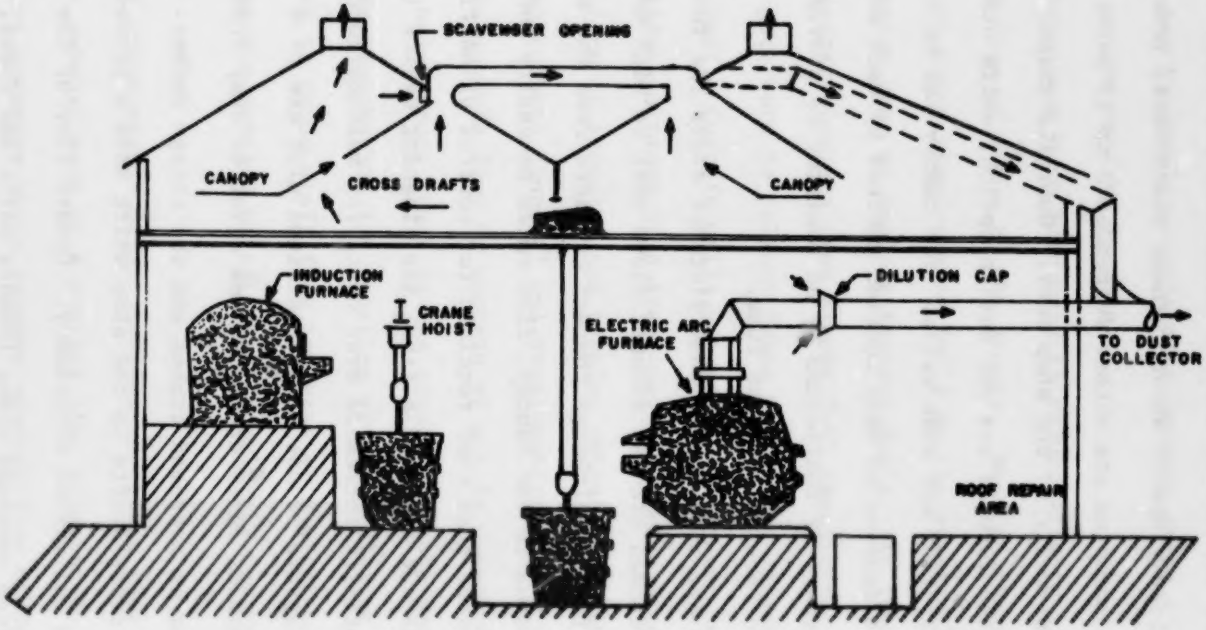

SCAVENGER OPENING
CANOPY
CROSS DRAFTS
CANOPY
INDUCTION FURNACE
CRANE HOIST
ELECTRIC ARC FURNACE
DILUTION CAP
TO DUST COLLECTOR
ROOF REPAIR AREA

Figure 3-4. Canopy Hood Using Building Roof as Part of the Canopy, Combined with Direct Furnace Evacuation

The configuration and proper location of a canopy is dependent mainly on structural and geometric considerations within the shop. Clearance for overhead cranes and furnace electrodes must be maintained and thus, the most effective position, closely spaced above furnace electrodes, generally cannot be attained. Rather, canopies are either suspended 7 to 13 meters above the furnace, or attached directly to the shop roof. Umbrella-shaped hoods of a diameter larger than the furnace are one design option, while other designs incorporate the foundry roof and side walls. The canopy can be constructed in sections with separate dampers to vary suction exerted by each section. Dampers can then be preset or controlled by an operator to provide a greater suction to areas which receive the most fume.

Because canopies are constructed some distance above the furnace to provide clearance for overhead cranes, exhaust flows must be high to ensure effective capture of fumes. Although thermal currents from the hot furnace help direct fumes upwards to the canopy, flow rates necessary for fume capture are several times greater than that required for control of melting emissions. Consequently, the size and costs of a final gas cleaning device (normally a baghouse) are substantially increased over costs for melting control.

Effective fume capture is not always attained with use of a canopy hood. As the furnace is charged, fumes are sometimes diverted away from the canopy because of impingement on overhead cranes and the charge bucket. Another problem is caused by cross drafts in the shop which have a pronounced, adverse effect on canopy hood collection efficiency. Upward flow of the fume is easily disrupted by drafts from openings along foundry walls and doors, passage of shop vehicles, and even suction hoods which may ventilate other nearby foundry processes. High pressure systems and low humidity tend to allow efficient upward flow of fume to the canopy. However, during periods of low pressure, high humidity, or strong winds, thermal columns above the furnace may not be sufficient to carry fumes directly into the canopy. For small furnaces, a canopy hood is not generally as effective because there is less thermal uplift generated by the smaller furnace.

Several techniques have been used to reduce effects of cross-drafts and improve upwards flow of fumes to the canopy. Many of these techniques are more prevalent at large steel-making EAF's at the steel mill, since emissions are usually greater than at smaller foundry EAF's. At foundries it is common to provide scavenger openings (see Figure 3-4) immediately above the canopy in the exhaust duct work to collect fumes which have escaped and accumulated under the shop roof. Curtain walls constructed of sheet metal have been used to screen sensitive portions of a steel-making furnace area from drafts and improve upward flow of charging and tapping emissions.[3] Another technique recently applied to both foundry[4] and steel-making[5] EAF's is the use of an air curtain. An upwards flow or curtain of air is directed around the furnace to contain and help direct fumes to the canopy. Mobile air curtains have provided an effective method for locating proper positions or counteracting daily variations in cross draft flow patterns at a steel-making shop.[6] Unfortunately, the air curtain often cannot completely overcome the force of cross drafts.

Control of cross-drafts often involves reworking shop ventilation systems. For example, an exhaust hood of a pouring line adjacent to a furnace may create a negative pressure which impedes upwards flow of fume from the furnace. At many foundries, the scrap handling area is adjacent to the furnace and has large doors which open to the atmosphere. Influence of outside winds on canopy efficiency must be reduced by closing these and other openings in the foundry walls.

Particulate collection and removal efficiency attainable with canopy hoods were evaluated during a research and development program conducted by a large British steel company.[7] Canopy hood size and exhaust flow rates were optimized in the development program, and it was determined that 90 to 100 percent of charging and tapping emissions were collected under optimum conditions. However, during periods of strong prevailing winds outside the shop, up to 30 percent of charging and tapping emissions drifted away from the canopy. To control the influence of cross-drafts deflecting the rising plume, vertical sheeting was installed over the entire length of a four-furnace melt shop, roof vents were blocked off, and doors fitted on large openings in the shop wall.

Table 3-2 summarizes exhaust flow rates and particulate removal efficiencies for canopy hoods and other control techniques for charging (and tapping) emissions. Exhaust requirements for canopies are high, ranging from about 65 m^3/sec (140,000 acfm) for a 3.9 Mg/hr furnace to 81 m^3/sec (172,000 acfm) for the large 22.7 Mg/hr furnace. Larger furnaces require proportionally less flow than the smaller because of the benefits of thermal uplift provided by the larger heat source. Flowrates shown are averages of typical values since the physical layout of a particular foundry dictates canopy location and size, and also flowrates. Collection efficiency of the canopy is listed at 80 to 90 percent; with 80 percent considered a typical level because of potential for fume deflection by cross-winds. Efficiency can be much lower for improperly designed canopies, especially in shops which do not control cross-drafts.

TABLE 3-2. TYPICAL EXHAUST FLOW RATES AND PARTICULATE REMOVAL EFFICIENCY OF CHARGING AND TAPPING CONTROL DEVICES AT MODEL FOUNDRIES

	Typical exhaust flow rate for model furnaces in m^3/sec			Particulate removal efficiency (percent)	
	Model furnace size				
	3.9 Mg/hr	9.1 Mg/hr	22.7 Mg/hr	Range	Typical maximum
Canopy hoods, charge and tap[1,7]	65.1	73.2	81.0	80-90	80*
Building evacuation, charge and tap[1,8]	81.0	91.5	101	95-100	99
Furnace enclosure charge[1]	22.8	25.6	28.3	95-100	99
tap				90-95	90
Close capture hoods charge[1]	12.9	19.8	50.0	60-90	80
tap				60-90	80†
Ladle pit enclosure, tap only[1]	12.9	19.8	50.0	90-100	99

*Collection efficiency substantially reduced if cross-drafts are present in shop.

†Tapping efficiency considerably reduced with increasing alloy additions to ladle; i.e., at steel furnaces.

Retrofitting an existing furnace with canopy hoods sometimes requires extensive structural modifications. Trusswork and roof beams must often be relocated, reconstructed and/or strengthened to accommodate the canopy and exhaust duct work. In some shops, there may not be enough clearance between the crane and the roof, or the roof configuration itself may not be adaptable to a canopy installation. Also, space must be provided for the baghouse which will necessarily be of a large size to handle the high exhaust volume.

3.3.2 Complete Building Evacuation

Several large iron foundries operate ventilation systems which completely evacuate the shop, exhausting fumes from charging, tapping and other foundry operations to a gas cleaning device.[4,9] Building evacuation systems are similar to canopy hoods but operate at greater flow rates, exhausting fumes which accumulate under the shop roof. Factors which influence installation of building evacuation over other systems for control of charging and tapping emissions are:

- Insufficient space, or structural limitations to use of a canopy-hood
- Need to collect other fugitive or miscellaneous emissions
- A roof configuration well suited to complete evacuation. Often, the roof can be modified to serve as a collection hood, as shown previously in Figure 3-4
- Desire to exhaust the entire foundry internal atmosphere to reduce pollutant concentration for reasons of industrial hygiene and also to reduce heat stress.

Major considerations in design of a building evacuation system are control of air flow patterns through the building and maintenance of an effective flow rate. Ideally, floor level air inlets surround sources of heat and the fumes are exhausted to a central outlet located overhead in the shop roof. However, compromises in the ideal situation are usually necessary because of structural and shop operational constraints. Excessive turbulence and dead zones must be avoided to ensure proper removal of fumes. Flow control is enhanced by isolating emission sources with partitions constructed to provide maximum feasible containment without interferring with foundry operations. These concepts are illustrated in Figure 3-5.

Air velocity through inlet openings of the building must be adequate to induce flow through proper locations of the shop. Louvers or vertical traveling adjustable doors are sometimes used as inlet openings through building external walls. Air outlets in the roof can be designed to avoid the necessity for large evacuation hoods, relying on the building roof truss area or plenum as a fume reservoir and collection chamber.

The volume of air typically withdrawn for building evacuation systems is difficult to generalize because each foundry is of a different size and building configuration. To maintain a clean internal atmosphere, about five air changes per hour is a typical design factor at steel mills.[10] Data developed for steel-making, EAF shops shows that typical building evacuation systems evacuate about 25 percent more air than an efficient canopy hood. This criterion was used for flow rates summarized in Table 3-2, 81 m^3/sec (170,000 acfm) for the small 3.9 Mg/hr furnace, ranging to 101 m^3/sec (214,000 acfm) for the large 22.7 Mg/hr furnace. Particulate collection efficiency is listed in Table 3-2 as typically 99 percent, ranging from 95 to 100 percent, in recognition of the fact that a few small openings may exist through which some emissions escape.

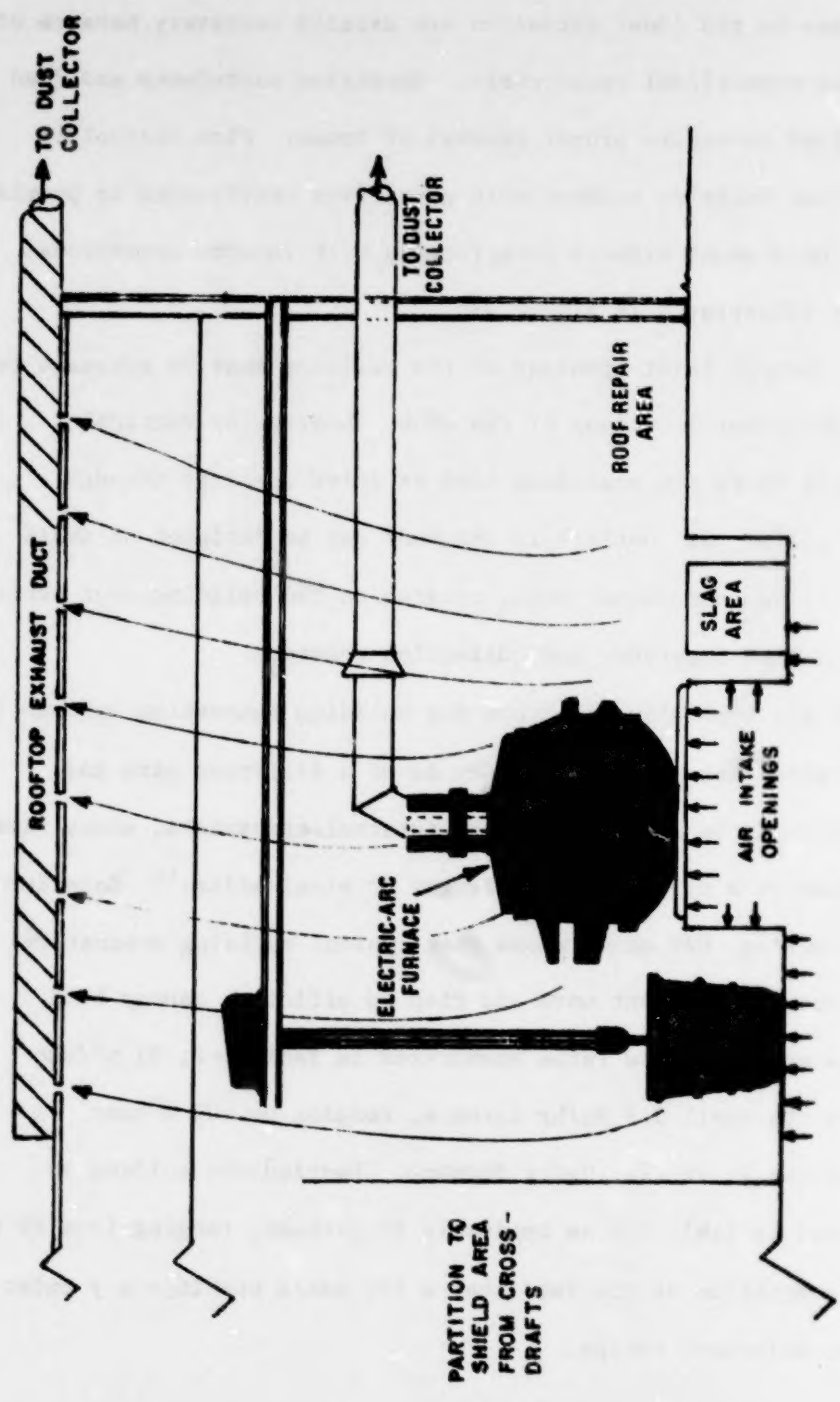

TO DUST COLLECTOR
TO DUST COLLECTOR
ROOFTOP EXHAUST DUCT
ROOF REPAIR AREA
SLAG AREA
AIR INTAKE OPENINGS
ELECTRIC-ARC FURNACE
PARTITION TO SHIELD AREA FROM CROSS-DRAFTS

Figure 3-5. Design Aspects of Building Evacuation System

There is a trend towards enclosing roof monitor vents to contain charging, tapping and other fugitive emissions and avoid violation of visible emission codes. A multiple, manifold-type exhaust system ducts contained fumes to the gas cleaning device, normally a baghouse. These systems are not designed as complete building evacuation systems, but are intended to simply remove fumes which accumulate under the shop roof. In this manner, charging, tapping and other fugitive furnace emissions are eliminated at an exhaust flow rate somewhat less than complete building evacuation systems since the exhaust flow rate is only adequate to remove accumulated fumes, not to evacuate the entire building. Although most emissions are collected and removed, a small amount will often escape the foundry through open windows and doors. The new Michigan casting facility of Ford Motor Company[11] is an example of this type of charging (and tapping)control.

3.3.3 Furnace Enclosure

A metal shell which completely encloses the furnace and tapping area can effectively capture emissions from melting, charging, and tapping. A large exhaust duct or hood near the enclosure top removes charging and melting emissions while a separate, local hood contains tapping fumes. Tapping fumes are collected by diverting exhaust flow from the enclosure to a local hood adjacent to the ladle. Several pairs of sliding doors allow entry of the charge bucket by conventional crane, and also provide for slagging, chemical addition and oxygen lancing.

The first domestic application of the shell enclosure concept began operation in 1976 on two 60-ton capacity steel-making EAF's at the Lone Star Steel Company, Lone Star, Texas. The furnaces are part of a new melt shop and each furnace was enclosed as an economical alternative to canopy hoods for control of charging and tapping emissions. Furnace enclosures have not yet been installed in foundries.

Furnace enclosures collect charging and tapping emissions with an air volume 30 to 40 percent of that required by an efficient canopy hood, considerably reducing both capital and operating costs for exhaust duct work, fans and gas cleaning device. These savings are partially offset by the greater capital cost of the enclosure, compared to canopy hoods or building evacuation. Major factors which reduce effectiveness of a canopy hood, namely, cross-drafts and diversion of fumes by the crane, are eliminated with a shell enclosure. As a secondary benefit, furnace noise is somewhat reduced outside the enclosure.

Figure 3-6 shows the basic design at Lone Star Steel Co., and pertinent design parameters are summarized in Table 3-3. Constructed of riveted steel plates, each enclosure is a cube with a domed or rounded top measuring 44 feet on edge. The enclosures contain the minimum volume which provides clearance for furnace roof removal during charging and for furnace electrodes when tilted for a tap. Pneumatic cylinders operate large vertical doors on the front of the enclosure, and an electric motor operates a segmental, horizontal, cable-guided top door to allow furnace charging by conventional crane. Smaller vertical doors at rear of enclosure allow access for oxygen lancing, slagging and chemical additions.

When charging, the crane operator has a line of sight to the furnace through the top enclosure doors. Final positioning of the charge bucket is aided by radio contact with a worker inside the enclosure. When a charge is dropped into the furnace, the front, charge doors are closed but the top, horizontal door remains open. A fan-type air curtain directs fumes past the

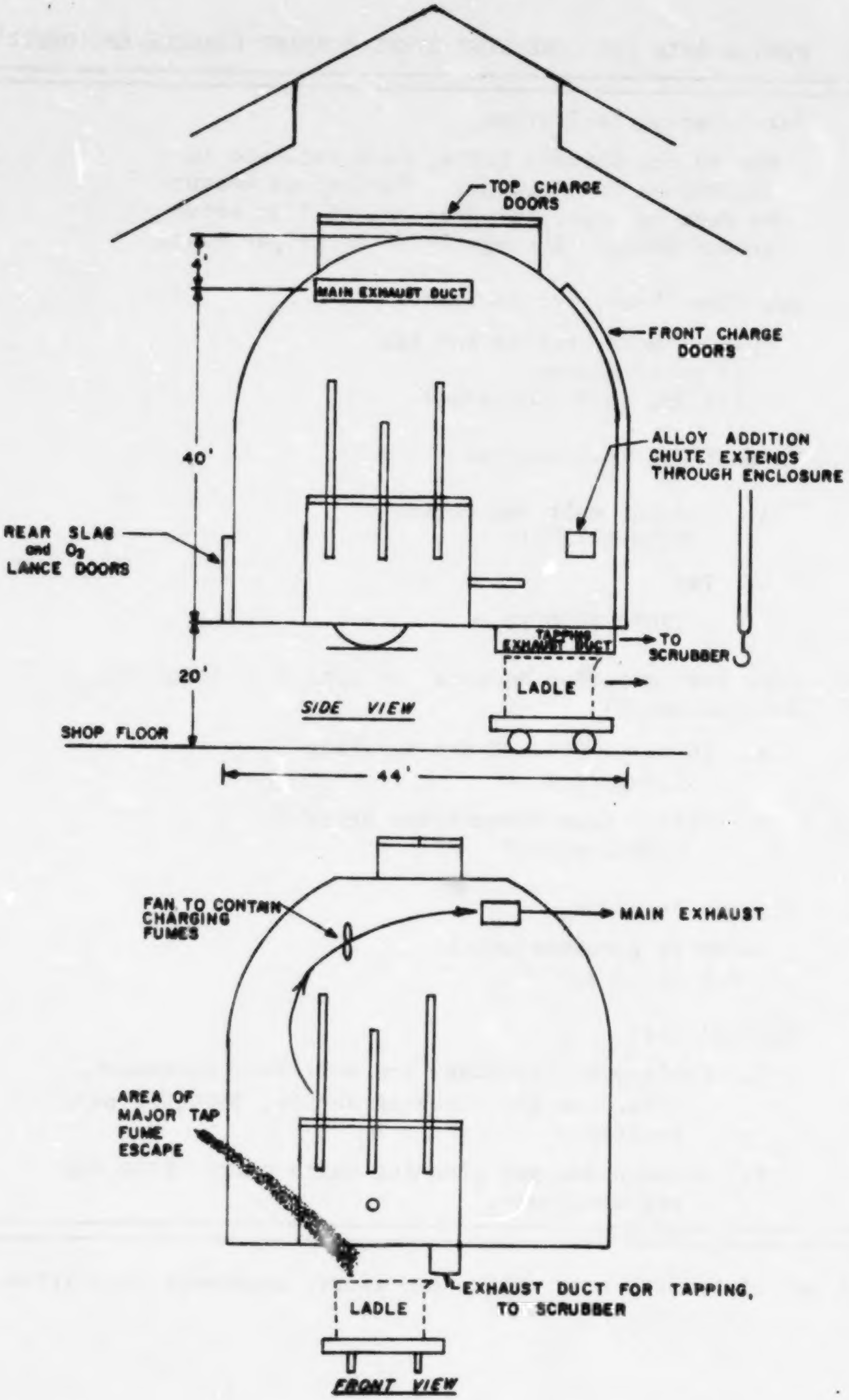

TOP CHARGE DOORS
4'
MAIN EXHAUST DUCT
FRONT CHARGE DOORS
40'
ALLOY ADDITION CHUTE EXTENDS THROUGH ENCLOSURE
REAR SLAG and O_2 LANCE DOORS
TAPPING EXHAUST DUCT
TO SCRUBBER
20'
LADLE
SIDE VIEW
SHOP FLOOR
44'
FAN TO CONTAIN CHARGING FUMES
MAIN EXHAUST
AREA OF MAJOR TAP FUME ESCAPE
LADLE
EXHAUST DUCT FOR TAPPING, TO SCRUBBER
FRONT VIEW

Figure 3-6. Sketch of Furnace Enclosure Design at Lone Star Steel Co.

TABLE 3-3. DESIGN DATA FOR LONE STAR STEEL COMPANY FURNACE ENCLOSURE[12]

I. Steel-Making Facilities

Two 60 ton Whiting EAF's, each enclosed in 114,000 cu ft enclosure. Enclosures measure 44 feet on edge; furnaces are 20 feet above ground level. Average 2-1/2 hours per heat.

II. Gas Flow Rate, per Enclosure

Charge, melt, refine and tap
35 to 42 m^3/sec
(75,000 to 90,000 afcm)

III. Exhaust Gas Temperatures

A. Charge, melt and refine
80°C (175°F)

B. Tap

120°C (250°F)

IV. Dust Concentration Measured by Lone Star Steel Co. (EPA Method 5)

A. Inlet to Steam-Hydro Scrubber
1.0 gr/scf

B. Outlet from Steam-Hydro Scrubber
0.0045 gr/scf

V. Suction Required

Inlet to scrubber units
7.5 in. w.g.

VI. Capital Cost

A. Enclosures, ducting, and auxiliary equipment, excluding gas cleaning device, $900,000 per enclosure

B. Steam-Hydro gas cleaning units only: $200,000 per enclosure.*

---

*Utilized existing waste heat boiler and slurry treatment facilities.

open top doors to the exhaust duct. During melting, doors are closed and fumes are exhausted from the enclosure by a large rectangular exhaust duct located 1.2m (4 ft) below the enclosure top, above the furnace. Between 75,000 and 90,000 afcm is withdrawn from each enclosure by suction developed by Lone Star's proprietary Steam-Hydro scrubber which cleans furnace exhaust. Slagging, chemical additions and oxygen lancing are conducted through a third set of doors at the furnace rear. The furnace is tapped in a ladle which is placed on a rail car by the overhead crane, then rolled into position under the enclosure. Tapping fumes are collected by diverting flow from the main exhaust duct to a hood which is adjacent to the ladle. Both furnaces and enclosures rest on a platform about 6.3m (20 ft) above the melt shop floor. This provides room for the tapping ladle car and also provides air flow from underneath the furnaces to effectively carry fumes to the main exhaust duct.

Lone Star Steel has encountered no major problems in using the enclosures. Almost all charging emissions are contained by the enclosure and exhausted from the shop. Presently, only clean, in-plant steel scrap is used as charge. Lone Star has run trial heats charging No. 2 bundles (autobodies processed through a compactor). Because of combustion of contaminating oil and organic matter, flames from the hot furnace reached to the top of the enclosure. Lone Star indicated that the trial runs showed additional enclosure height would be necessary if dirty scrap were to be used routinely. When clean scrap is charged, roughly 95 to 99 percent of charging emissions appear to be collected. This estimate is based on observations of engineers who visited the plant on behalf of EPA, and on statements of plant engineers, and the local air pollution control agency.[12]

Melting emissions are also effectively contained by the enclosures. When viewing the enclosure interior during melting, fumes appear to flow directly upwards in a column towards the exhaust duct near the top. The space around the inside perimeter of the enclosure is relatively free from fume, as the rising column does not fill the entire enclosure. Flames and fumes violently escape furnace electrode holes during melting. The absence of visible emissions from the top of the enclosure suggests that almost 100 percent of melting emissions are captured. Opening of rear enclosure doors for oxygen lancing or slagging did not noticeably affect the uniform flow of melting fumes upwards to the exhaust duct.[12]

Fumes generating during tapping appear considerably greater in magnitude than charging emissions. A tap lasts 6 to 8 minutes. Alloys are continously added to the ladle through a special chute extending through the enclosure side. Tapping fumes are drawn laterally into a rectangular side draft hood adjacent to the ladle top. Most fume was drawn into the hood, as the entire 75,000 to 90,000 cfm exhaust rate is diverted from the enclosure to the tap hood, and capture velocity is quite high. Roughly, 10 percent of tapping fumes escape collection, exiting the enclosure primarily through the alloy addition chute, and to a lesser degree, through enclosure doors. Fumes escaping the alloy addition chute dissipate substantially by the time they reach the melt shop roof. Lone Star's smoke observers have read opacity of fumes escaping the roof monitors ranging from 0 to 40 percent during tapping, averaging about 8 percent.[12]

Another steel-making EAF enclosure was scheduled for operation in Europe in 1977. This system, shown in Figure 3-7, is offered by the Krupp Co. It relies on an enclosure somewhat larger than at Lone Star Steel. A direct roof

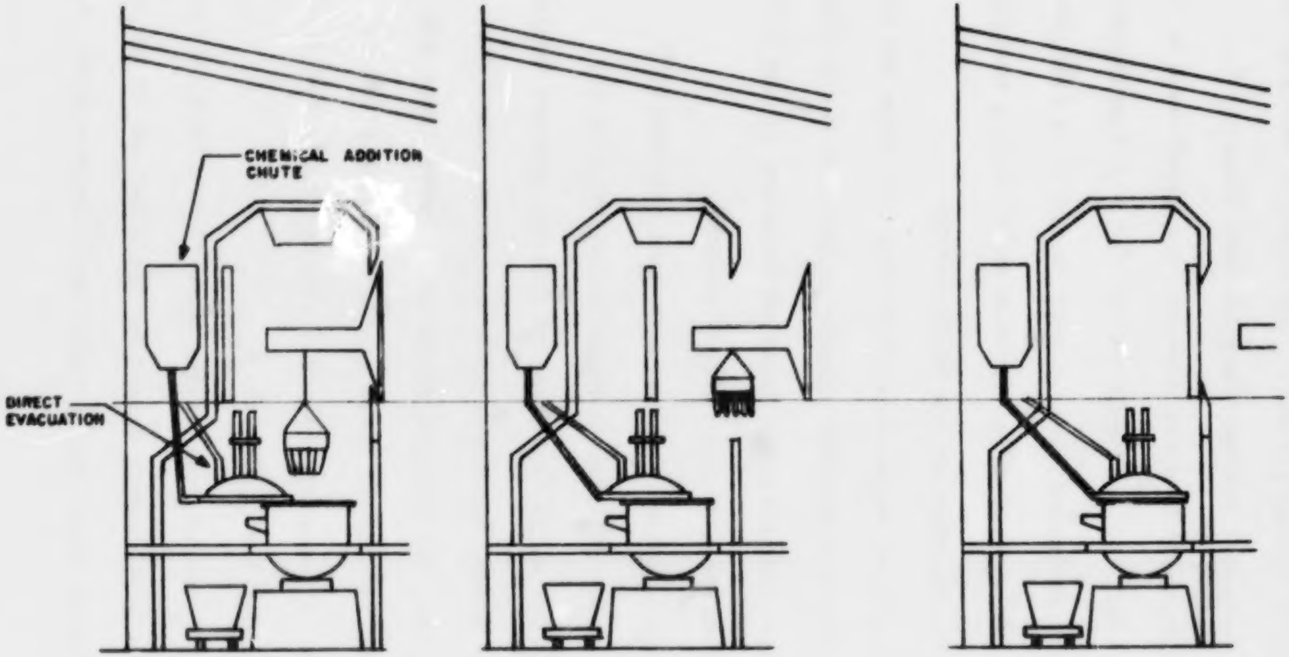

CHEMICAL ADDITION CHUTE
DIRECT EVACUATION

Figure 3-7. Krupp Furnace, Sequence of Events During Charging

evacuation tap supplements fume control during melting. Instead of sliding doors, a section of the enclosure side wall moves horizontally to allow passage of a specially-designed charging crane. The crane is designed with a section which seals the enclosure during charging (see Figure 3-7). Procedures for tapping and alloy additions are similar to methods used at Lone Star. Available data indicates that the enclosure volume for a 128 megagram (140 ton) steel EAF is 11,000 m^3 and enclosure exhaust rate is 135 m^3/s (290,000 afcm) during charging and tapping and 105 m^3/s (226,000 acfm) during melting. No other details are readily available on the Krupp design.

While the enclosure concept appears to be a very effective method for capturing furnace emissions with minimum exhaust volume, it would either be difficult to retrofit this technology to existing furnaces or the effectiveness of the system would be reduced for several reasons:

- Lack of adequate space at existing furnaces may preclude installation of the enclosure, which is larger than the furnace. Adjacent walls, furnaces or foundry process equipment would, in many cases, interfere with enclosure placement.
- At most foundries, the furnace rests on the shop floor and the tapping pit is located below grade. Tapping pits may be too small to accommodate the rail car necessary for carry- in the ladle under the enclosure.
- Where existing furnaces rest on the shop floor, airflow through the bottom of the enclosure cannot be optimized as in the case of Lone Star Steel where the furnaces are 6 meters above the shop floor.

- Location and configuration of charging cranes may not be amenable to operating around and within the enclosure.
- Slagging, alloy addition and oxygen lancing procedures must be somewhat modified with use of an enclosure, but this is of minor importance.

3.3.4 Close Capture Hoods

The "close capture" concept for controlling charging, melting and tapping emissions, as supplied by the Hawley Manufacturing Company, is illustrated in Figure 3-8.[13] Melting and refining emissions are evacuated by a circular hood which completely encompasses the electrodes, unlike conventional side draft hoods which are open on one side. This allows improved collection of fumes with minimum exhaust volumes. Capture of charging emissions is accomplished by an annular hood which encompasses the furnace roof ring during charging. The charging hood is designed to rotate onto the furnace during a charge, and then rotate back to the furnace side during melting. Charging fumes are withdrawn radially through slots in the inner hood circumference; the slots serve to increase capture velocity and improve fume collection. When charging, dampers in the exhaust duct work divert the exhaust flow from the circular hoods to the charge hood.

Tapping emissions are collected by enclosing the tap spout with an inverted u-shaped hood which is exhausted through one of the vertical sides. When charging or tapping, dampers divert most of the exhaust flow from the electrode hood to the charge or tapping hoods. A telescoping joint allows the electrode hoods to withdraw a moderate amount of fume from the furnace during tapping, supplementing the tapping hood exhaust. The tap hood only encloses the furnace tap spout and a portion of the ladle, as opposed to

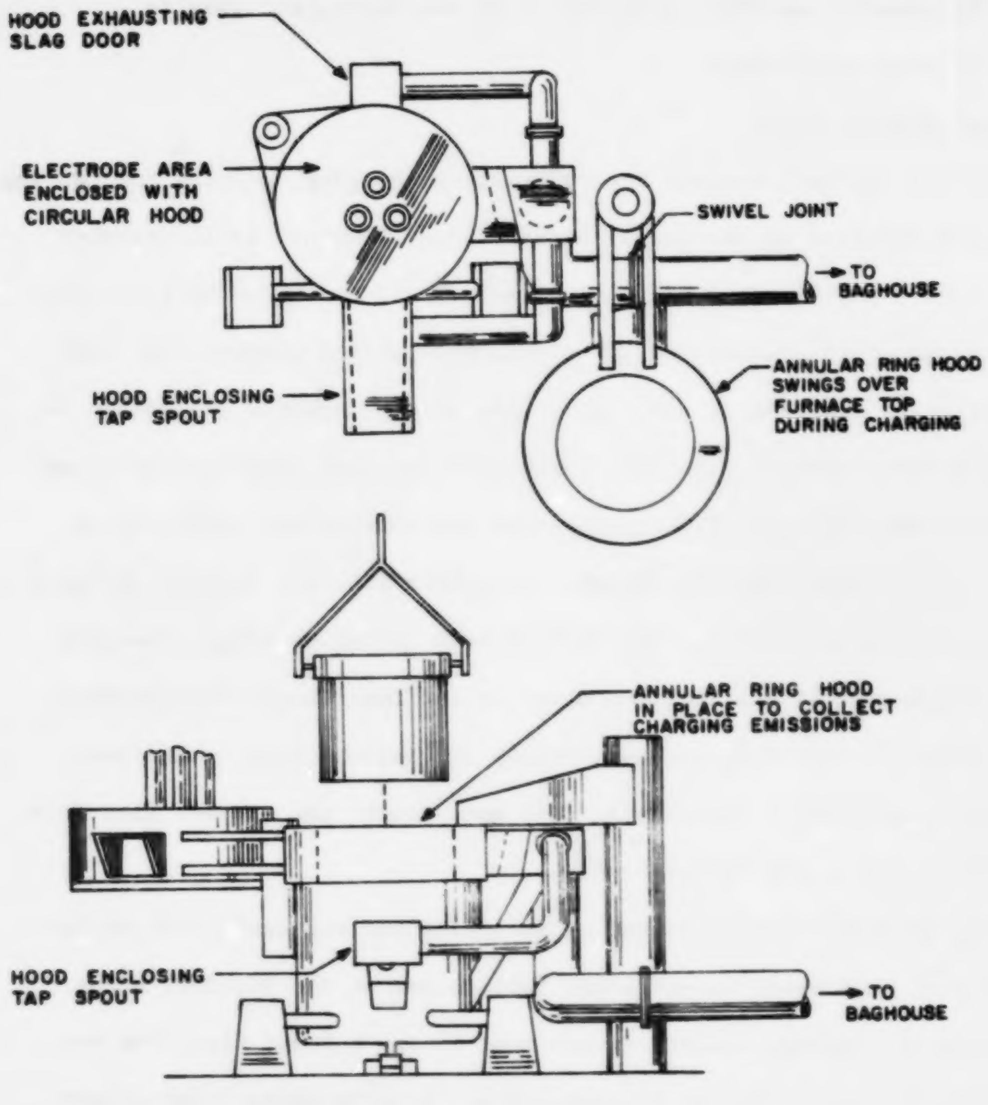

HOOD EXHAUSTING SLAG DOOR
ELECTRODE AREA ENCLOSED WITH CIRCULAR HOOD
SWIVEL JOINT
TO BAGHOUSE
ANNULAR RING HOOD SWINGS OVER FURNACE TOP DURING CHARGING
HOOD ENCLOSING TAP SPOUT
ANNULAR RING HOOD IN PLACE TO COLLECT CHARGING EMISSIONS
HOOD ENCLOSING TAP SPOUT
TO BAGHOUSE

Figure 3-8. Hawley Close Capture Hoods

other designs (furnace enclosure, ladle pit enclosure) which enclose the entire ladle for more complete fume containment. A small, separate hood is also provided for the slag door.

The advantage of the close capture design is that control of charging and tapping are provided at an exhaust flow rate much less than for canopy hoods or furnace enclosures. This significantly reduces the quantity of exhaust gas delivered to the particulate control device, thus reducing costs of gas cleaning. Also, the close capture hoods are simpler and considerably less expensive to install than a furnace enclosure or canopy hood. The disadvantage is the complete control of charging and tapping may not always be provided because the charge/tap hoods do not completely enclose emission sources.

Exhaust flow rates of the close capture design are comparable to those used with conventional side draft hoods. For example, a 3.9 Mg/hr model furnace would require about 12.9 m^3/sec (27,400 acfm) for the close capture hoods, contrasting sharply with 65 m^3/sec for canopy hoods and 23 m^3/sec for a furnace enclosure. The manufacturer guarantees total particulate removals of 100 percent for melting and 80 percent for charging and tapping (of iron). However, these efficiencies have not been verified by EPA. As alloys are added to the ladle (i.e., steel foundries), tapping control efficiency is expected to be substantially reduced. Control of backcharging is also likely to be less than 80 percent.

The close capture design is applicable to most new foundries where the furnace area can be designed to accomodate the hoods. The close capture design has recently been applied to several foundries. At one particular steel foundry, visited by representatives of EPA,[14] there was not enough clearrance between the furnace and the transformer room wall to allow employment of the annular charging ring. In this retrofit case, only a partial charging hood could be used, mounted to the furnace shell to partially encompass charging emissions. Collection efficiency of charging emissions was observed to be substantially lower than that expected from the complete charging hood. Many existing foundries will likely have similar space restrictions which limit control options such as the Hawley design (and also furnace enclosures, and certain other options).

3.3.5 Control of Charging Emissions by Use of Clean Scrap

Charging clean scrap to an EAF substantially reduces charging emissions. When dirty scrap contacts a hot furnace, oil and other volatile impurities combust, releasing dense clouds of soot and smoke. Oily scrap can also cause premature roof failure around electrode ports, damage dust evacuation hooding and ducts and also clog or "blind" a fabric filter control device. Use of dirty, substandard scrap has been estimated to increase overall furnace emissions by up to 100 percent - although quantitative test data for charging emissions are generally not available.[15] Contact with several state and local air pollution agencies indicated that quite often, foundries are required to use a clean scrap to control charging emissions.[16] For example, the Los Angeles County Air Pollution control district issues operating permits to furnaces which use clean scrap as the method to control charging emissions. No visible emissions are detected at roof vents above the furnace during charging.

3.3.6 Preheating or Degreasing Scrap to Reduce Charging Emissions

Charge preheaters are standard equipment on induction furnaces for cleaning the charge, removing water, and avoiding operating problems of charging dirty scrap. Few preheaters are used in EAF foundries although they have been used overseas as a method for producing clean scrap for reduction of charging emissions on electric arc furnaces in foundries.

The most efficient preheater is the conveyor type which applies a fossil fuel flame to the scrap under a fume collection hood. The conveyor typically discharges clean, hot scrap to a charge bucket although a few systems have been designed to charge directly to the induction furnace.[17,18] Preheating in a special charge-preheat bucket has been used but does not result in uniform preheating. Ultra hot, intense flame jets must be directed into the scrap for certain periods to heat the entire charge, increasing the danger of over-oxidation of thin pieces of scrap. Excessively oxidized scrap requires considerably more energy for melting.

Some preheaters are designed with a secondary combustion chamber which acts as an afterburner for controlling emissions from the preheater. One manufacturer of preheaters for induction furnaces reports that air pollution codes of Los Angeles County are met by a local facility using this type of preheater. Emission data for preheaters is not readily available.[17]

Preheaters used for induction furnaces reportedly reduce overall power costs for melting because the preheaters more efficiently heat the metal, and costs for fossil fuel have traditionally been less than electricity. Net energy savings with preheaters have been quoted on the order of 75 kWh per ton of metal,[17,18] compared to normal melt requirements of about 500 kWh/ton.

Application of preheaters to EAF's will likely be severely limited by fuel shortages. Natural gas supplies to industry were severely reduced this past year, and many industries expect shortages throughout the next few years. Other gases, such as producer gas, if available, could be used also.

Retrofitting existing EAF's with a conveyor-type preheater could require substantial reconstruction of scrap bins and scrap bucket handling systems.

A degreasing process to remove oil and dirt from the charge can also be used to reduce emissions caused by dirty scrap. Degreasing operations involve washing scrap in a tank with either a solvent or detergent and water. Excessive amounts of oil may be removed from turnings and other machining wastes by centrifuging which typically reduces oil content to about 2 percent.

Degreasing has been traditionally used to remove oils from valuable scrap such as brass, bronze and copper, but is not usually applied to ferrous scrap at the foundry. Rather, degreasing is typically used by scrap dealers, as in the case of motor blocks which are often crushed and cleaned by the scrap dealer, then sold to the foundry.

Problems with use of degreasing at foundries center about disposal of solvent residues and air emissions of hydrocarbons from the solvents. About 2 to 5 pounds of solvent per ton of charge cleaned requires disposal, when boring and turnings are the charge material. Of more importance, the mass of solvent emissions from the degreaser has been estimated to exceed emissions which would be generated by charging of dirty scrap.[1] Thus, degreasing is not considered an environmentally acceptable option for reducing charging emissions from unclean scrap.

3.3.7 Briquetting to Reduce Charging Emissions

In many foundries, particularly steel foundries, up to about 20 percent of each charge is "swarf" - turnings and borings produced by machining of castings. The swarf itself is readily oxidized upon charging, and also contains oils from machining. Thus, charging swarf to the EAF results in greater generation of emissions, compared to charging of heavier scrap pieces. A briquetter can be used to compress the swarf into a more solid form which serves to minimize oxidation of metal during charging, thus reducing charging emissions. Briquetters are not common at foundries, and no data is available to quantitatively indicate potential reduction in charging emissions.

3.3.8 The Brusa Closed Charging System

The Brusa closed charging system, illustrated in Figure 3-9, has been operating on a steel-making furnace in Italy for several years.[19,20] Exhaust gases from the hot furnace are vented through a rotary kiln or drum. Charge material is fed continuously down through the kiln, into the furnace, and is preheated by furnace gases to about 1000°C. Volatile matter entrained in the charge is thus oxidized, and withdrawn at the top of the kiln along with furnace exhaust gases.

This system has the advantages of heat recovery, and containment of charging emissions in a fashion allowing for simple collection and ducting to a control device. However, this type of steel-making is the continuous process, where charge material is continuously added, and the furnace frequently tapped. There is a trend towards this type of operation in steel-making furnaces, but only one domestic foundry EAF is known to use continuous charging. The Brusa and other conceptual designs for closed charging systems require small-sized scrap in order to pass through the enclosed conveyor system.

3.3.9 Hooded Charge Bucket

The hooded charge bucket, illustrated in Figure 3-10, is designed to fit snugly over the top of the furnace during charging. Charging emissions pass

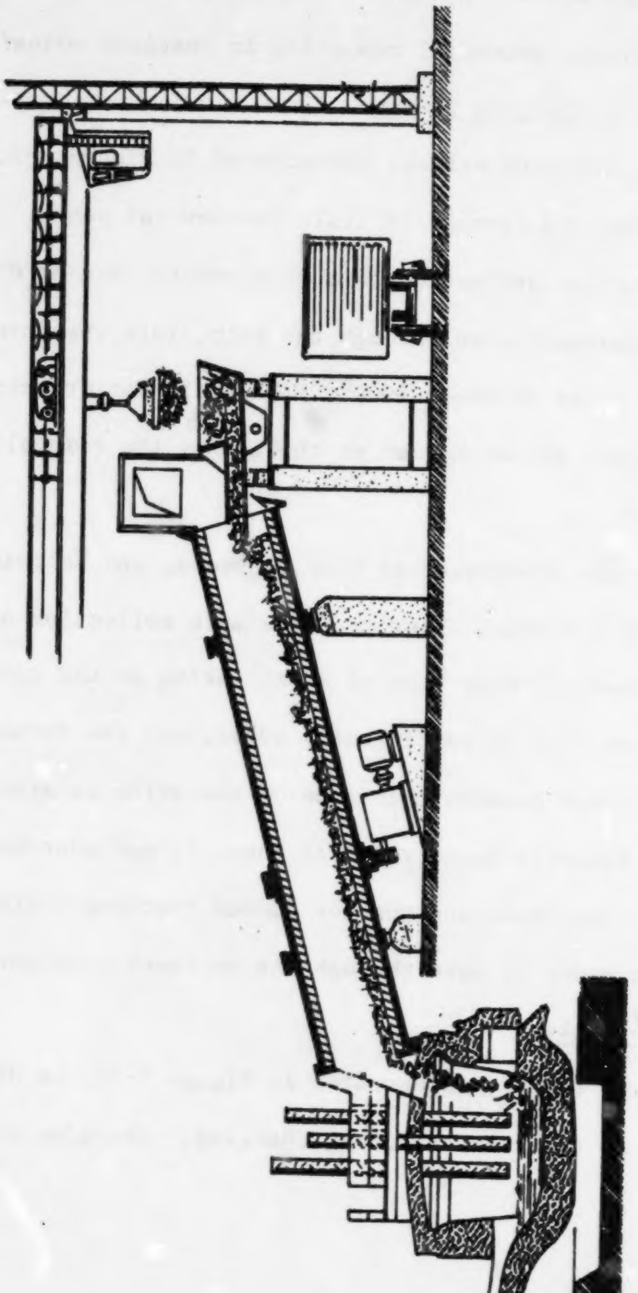


Figure 3-9. The Brusa Charging and Preheating System

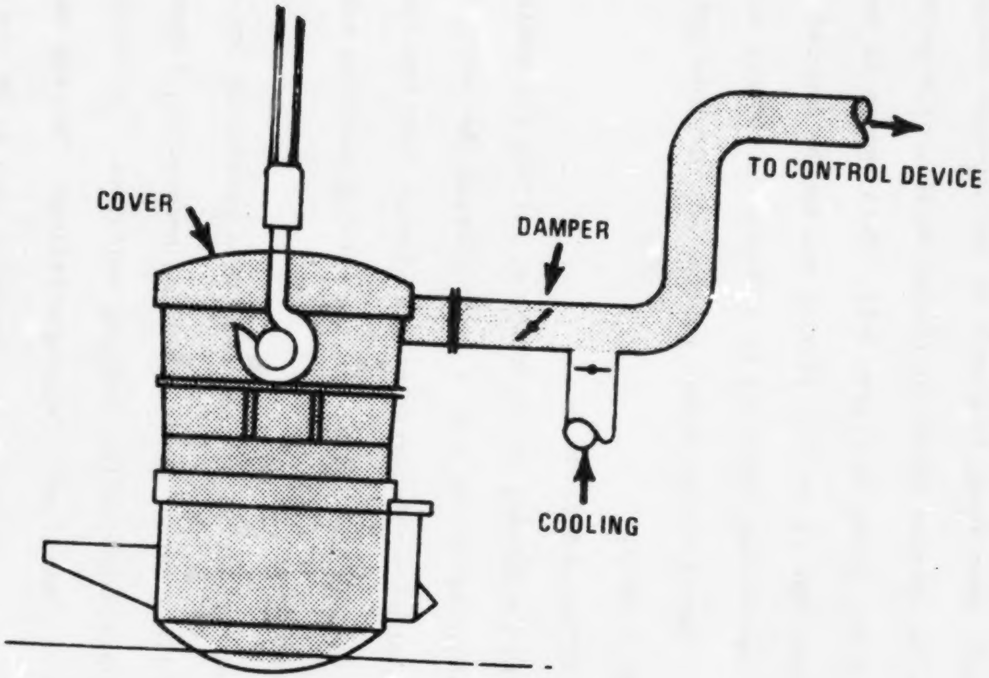

COVER
DAMPER
TO CONTROL DEVICE
COOLING

Figure 3-10. Hooded Charge Bucket

upwards through the bucket and into an attached hood. The majority of fumes evolved from charging would be collected and exhaust volumes would be substantially lower than with a canopy collector. While hooded charge buckets are commercially available,[21] none are known to be operating at present.

A similar approach under study in Europe is the Marchand design, a local, mobile hood which can be clamped above the charge bucket, or suspended over the furnace by overhead crane, shown in Figure 3-11. This system is very similar in function to a canopy, but is smaller in size and can be lowered close to the furnace, minimizing air volumes necessary to effectively capture the fumes. This variation of the hooded charge bucket concept has not been applied to foundry EAF's in this country.

3.4 COLLECTION OF TAPPING EMISSIONS

The EAF is tapped by raising the electrodes, tilting the entire furnace up to 45°, and transferring the melt to a ladle through the pouring spout. Sparks and fumes of molten metal particles are ejected from the flowing metal. Alloys are usually added to the ladle, and the ensuing reaction substantially increases tapping emissions.

Some of the fume collection systems described previously for control of charging emissions; i.e., canopy hoods, building evacuation, furnace enclosures and close capture hoods, also collect tapping emissions. At certain foundries, it may be desirable to control only tapping emissions. Tapping emissions can be collected by enclosing and exhausting the ladle pit, or by use of a tapping hood. Armco Steel Corporation holds a U.S. patent on a tapping pit enclosure, while several designs for tapping hoods have been used at steel-making furnaces. These tapping control systems are discussed below in more detail.

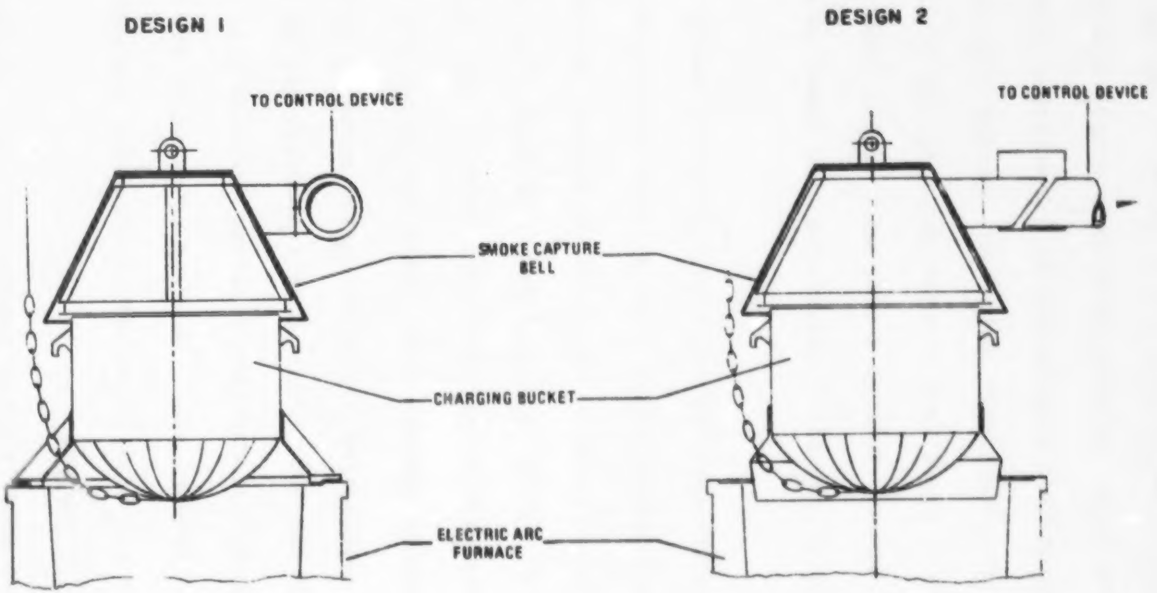

DESIGN I
DESIGN 2
TO CONTROL DEVICE
TO CONTROL DEVICE
SMOKE CAPTURE BELL
CHARGING BUCKET
ELECTRIC ARC FURNACE

Figure 3-11. Marchand Design for Charging Emission Control

3.4.1 Armco Steel Tapping Pit Design

Armco Steel Corporation was granted a U.S. patent[22] for the tapping pit enclosure shown in Figure 3-12. In this relatively simple design, the ladle is placed under the furnace in a tapping pit by conventional overhead crane. A powered, removable cover effectively seals the tapping pit after the crane is retracted. Molten metal flows from a short spout in the furnace to a launder, or chute which extends through a side wall of the ladle pit. An exhaust duct near the top of the pit withdraws tapping fumes to a gas cleaning device.

Armco Steel Corporation uses the ladle pit enclosure design at the Torrance, California steel-making plant. The exhaust flow which evacuates the furnace during melting is diverted to the ladle enclosure, and this provides a high capture velocity to remove tapping fumes. (Exhaust flow rates are thus comparable to those representative of side draft hoods.) The enclosure is designed to minimize openings through which fumes can escape and high particulate removals would be anticipated, about 90 to 100 percent, with typical optimum performance of 99 percent. While this technology can be easily designed into a new melt shop, retrofitting existing furnaces will depend largely on available space in the tapping area. At many shops there may be clearance problems when the tapping pit roof is retracted for ladle removal.

3.4.2 Hoods for Control of Tapping

Small umbrella-shaped hoods located immediately above the ladle can collect tapping emissions from the ladle area. This type of tapping hood is sometimes used with steel-making EAF's, but not at foundries. Such a design could be employed more frequently at foundries where tapping control is necessary.

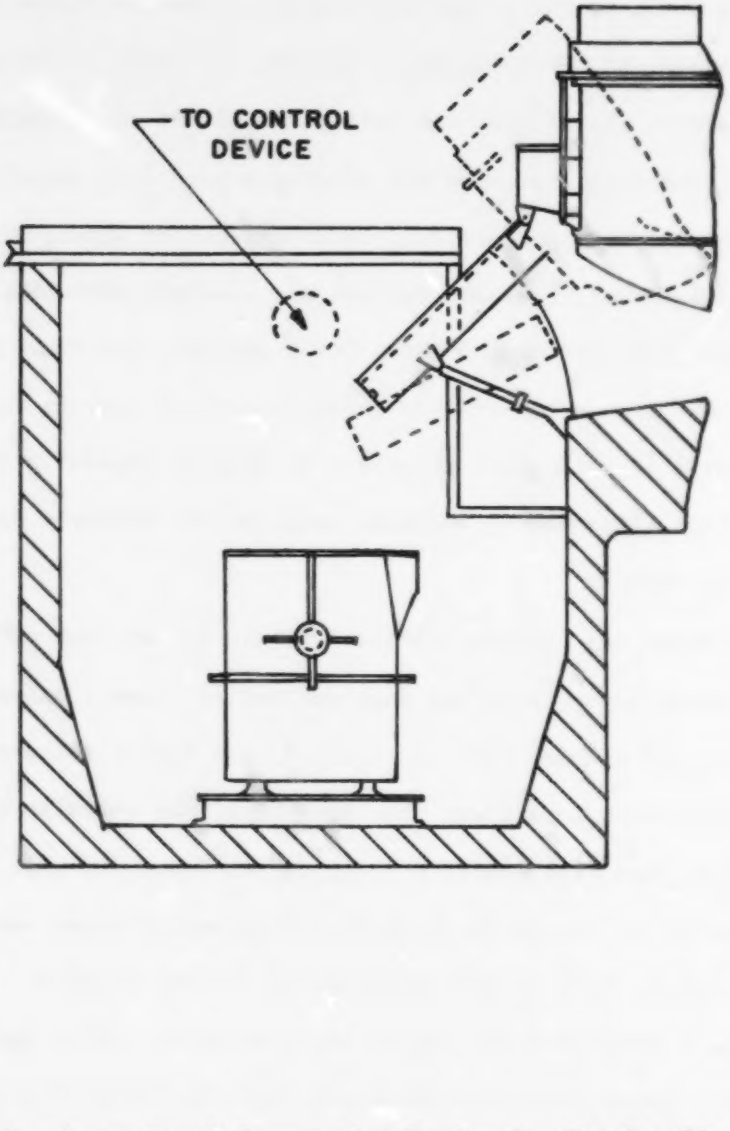

TO CONTROL DEVICE

Figure 3-12. Armco Steel Corporation Design for Tapping Pit Enclosure

There are several approaches to designing a tapping hood. Figure 3-13 shows one technique where a tapping ladle car receives the ladle by overhead crane, then is pushed into position underneath a permanent tapping enclosure. Such a system is most amenable to new foundries, as space limitations will often limit retrofit potential. Another concept, shown in Figure 3-14, involves a ladle placed in a tapping pit. Further, as shown, a two-piece hood mounted on a track is placed over the ladle, around the crane cables. Another design calls for removing the crane and placing a hood into position over the ladle. Flexible or easily matched duct work connections are required for both designs. In general, the hood systems are somewhat more complicated than the enclosed ladle pit (Armco Steel Corp. design), but there may be cases where a hood is the best approach when local control of tapping is necessary. Particulate removal efficiency of this type of hood at foundries is not known, but high collection efficiencies would be expected for properly designed hoods.

3.5 GAS CLEANING DEVICES

While each major gas cleaning device - fabric filter, wet scrubber, and electrostatic precipitator (ESP) has been applied to foundry emissions to some extent, virtually all foundry EAF's in the U.S. use fabric filters. Fabric filters use considerably less power than scrubbers, are normally more efficient collectors of fine particles characteristic of EAF fume, and also collect dust in a dry form which is readily disposed of. Scrubbers produce wastewater which must be treated prior to recirculation to scrubbing units. Electrostatic precipitators have received only limited application to EAF's, and mostly in other countries. Recent improvements in precipitator collection efficiency may increase interest in the U.S., but relatively high installation costs will likely preclude common use on electric arc furnaces.

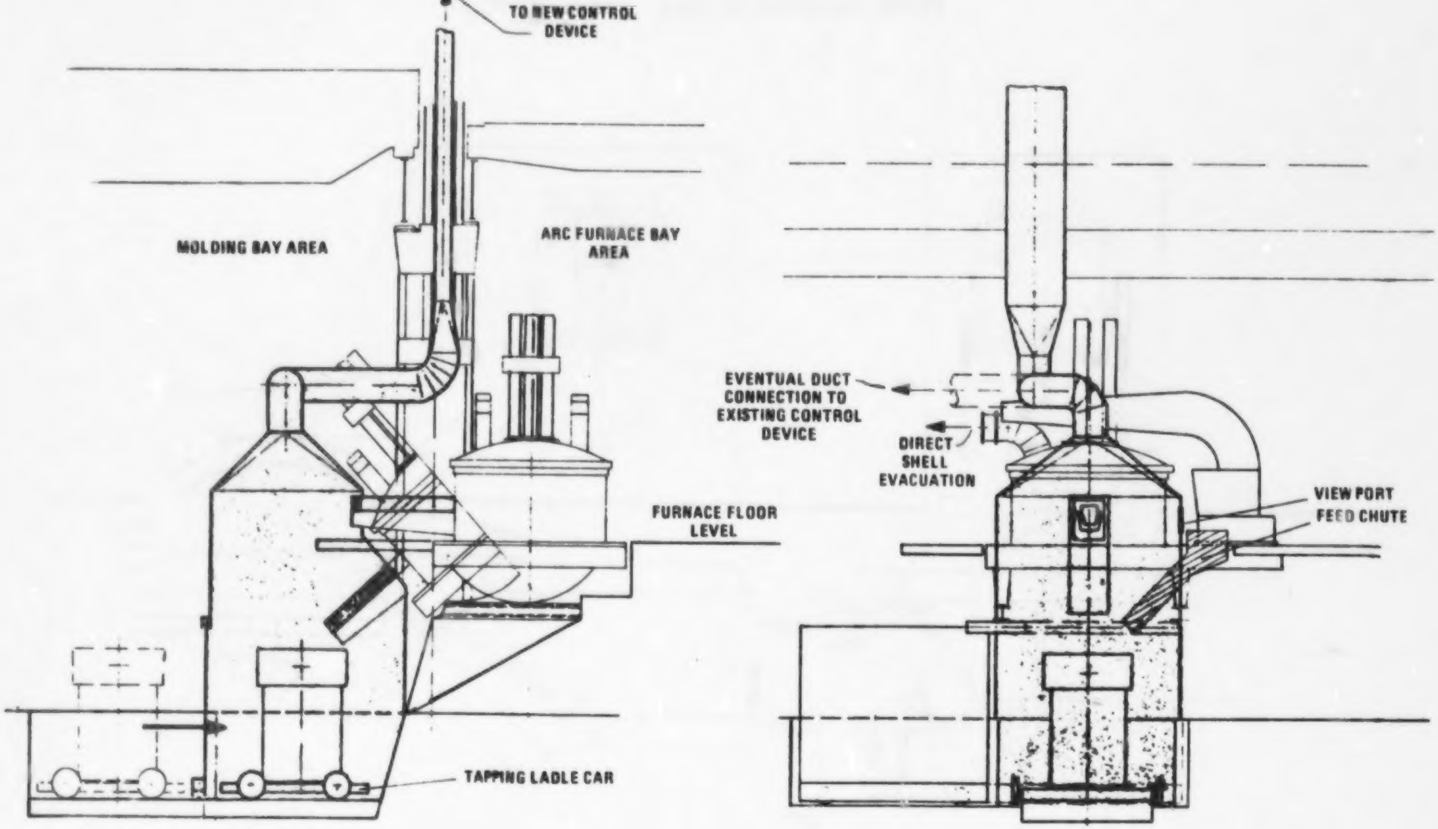

TO NEW CONTROL DEVICE
MOLDING BAY AREA
ARC FURNACE BAY AREA
FURNACE FLOOR LEVEL
TAPPING LADLE CAR
EVENTUAL DUCT CONNECTION TO EXISTING CONTROL DEVICE
DIRECT SHELL EVACUATION
VIEW PORT
FEED CHUTE

Figure 3-13. Ladle Car and Ladle Enclosure by Marchand

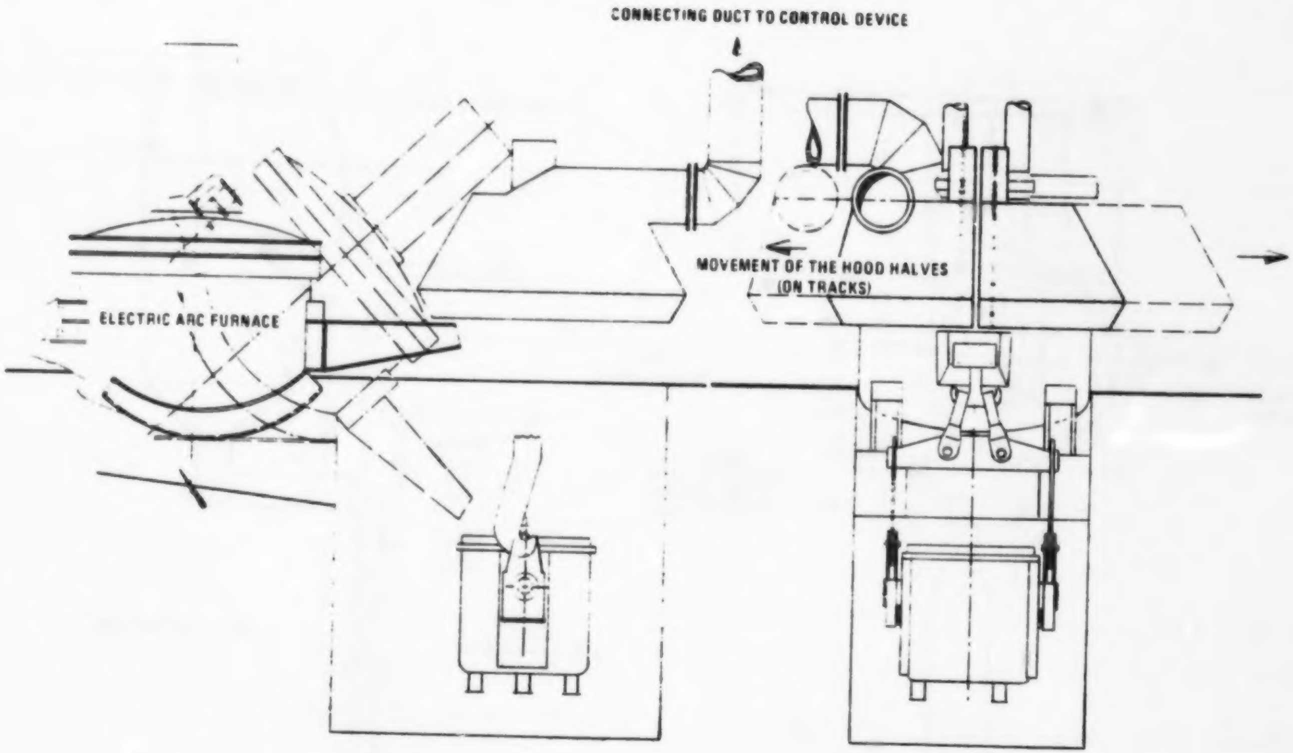

CONNECTING DUCT TO CONTROL DEVICE
ELECTRIC ARC FURNACE
MOVEMENT OF THE HOOD HALVES
(ON TRACKS)

Figure 3-14. Mobile Tapping Hoods

3.5.1 Fabric Filters

Exhaust gas from the EAF contains fine particulates dispersed in a gas stream that changes considerably in temperature, dust concentration and volume during the various furnace phases. Fabric filter collectors (baghouses) are regarded as the most versatile and efficient device for cleaning these fumes, because they are relatively insensitive to process variations. Baghouses can be operated under positive or negative pressure and are cleaned intermittently by shaking, reverse air flow or pulse jet mechanisms. Typical filter media used for bag construction includes woven or felted glass, Dacron or Orlon and other synthetic fibers.

Positive pressure baghouses force exhaust gas through the bags using a fan placed between the fume collection duct and the baghouse. Maintenance and bag inspection is easier than negative pressure units, as the baghouse is not airtight and can be entered while in service. Dirty gas enters the inside of each bag, is filtered through the cloth, then vented to the atmosphere through louvers or vents along the top of each compartment. New baghouses installed on EAF's tend to be the pressure type because of lower capital costs and simple inspection procedures for detecting damaged bags. With suction or negative pressure-type baghouses, a fan on the clean air side of the baghouse pulls air through the bags. Bag compartments must be kept airtight, and thus inspection for defective bags requires the compartment to be taken off line. Suction baghouses usually require less fan maintenance, and less operating horsepower than the pressure type.

Fabric filter bags periodically become clogged with a dust cake and require cleaning to avoid excessive pressure loss. So-called intermittent systems are designed to run without cleaning until the end of a furnace heat, at which time flow stops and the bags can be manually shaken. Intermittent baghouses generally cost less than, and are easier to maintain than the automatic continuous service baghouse. The intermittent filter is most applicable to small single furnace shops where there is adequate time between heats to manually clean the filter.

Automatic cleaning baghouses are much more common than intermittent systems as they are capable of continuous, unattended service, and precise control can be maintained over pressure loss and thus fume capture efficiency. Cleaning methods in common use are: mechanical shaking, reversing the air flow, and pulse jet mechanisms, all of which dislodge collected particles from the bags to a hopper located underneath.

3.5.2 Wet Scrubbers

Wet scrubbers mix and entrain particulates in the exhaust stream with water and collect dust laden water droplets by inertial mechanisms. There are two basic scrubber types - wet impingement and venturi. In a wet impingement scrubber, furnace exhaust gas enters through the scrubber bottom, is cooled in a water spray zone, and passes through one or more impingement baffles which separate dust laden water droplets from the gas stream. In a venturi scrubber, pressurized nozzles inject a water spray into the venturi section. Intense turbulence within the venturi constriction causes entrainment of particulates into the water droplets. The water-dust mixture is removed from the gas stream both within the venturi section itself and in a following cyclone separator. For either scrubber type, collection efficiency can approach 98 to 99 percent, but it is dependent on pressure drop (or energy expended) in the scrubbing (venturi) section.

Venturi scrubbers are commonly used with cupolas and steel-making basic oxygen and electric arc furnaces overseas, but there are no known installations on iron or steel foundry EAF's in the U.S.[8] Fabric filters are preferred over scrubbers for several reasons. Although installation costs and space requirements for the scrubber are somewhat lower, power costs are high, especially for high efficiency scrubbers which operate at high pressure drops. Disposal of scrubber wastewater requires water treatment and/or water recirculation systems at the plant. Most importantly, wet scrubbers are generally not as efficient as baghouses for collecting fine particles generated by the EAF.[8] Because of low capital costs, and low space requirements, high-efficiency scrubbers may be a useful control option for existing EAF's in areas of the country with low power costs.

There is one commercially available high energy scrubber which has been shown capable of meeting stringent concentration standards for an EAF. The Steam-Hydro scrubber (Lone Star Steel Company) achieves high removal efficiency on submicron particles by means of steam injected at supersonic velocity in a mixing section. This unit was designed to operate with waste process heat from an integrated iron and steel mill. Where sufficient waste heat is available, this scrubber appears quite economical as compared to fabric filters. However, in a foundry with only an electric arc furnace, waste heat from the EAF alone is sufficient to provide only a portion of the required energy.[12] An auxiliary fan must provide the remainder, about twice as much energy as a fabric filter system. Maintenance and capital costs are less for the scrubber, and this scrubber may be one alternative to the baghouse for efficient collection of the fine particulates from the EAF.

3.5.3 Electrostatic Precipitation

Electrostatic precipitators (ESP's) operate by electrically charging particulate matter and collecting charged particles on oppositely charged plates by coulombic attraction forces. The plates which collect particulates are periodically cleaned by mechanically shaking with hammers called rappers, or by flushing with water. ESP's are very efficient collectors of particles larger than several microns, but collection efficiency has traditionally dropped markedly for smaller particles. However, recent developments in ESP technology have improved performance for the smaller particulates. Successful ESP operation is strongly dependent on the electrical resistivity of the particles. Dusts from metallurgical processes must sometimes be wetted with water to decrease resistivity to an acceptable range.[23]

Installed costs for ESP's are somewhat greater compared to fabric filters while energy consumption is comparable for the two devices. Baghouse maintenance requires periodic bag replacement, but baghouses can normally operate continuously. ESP's, however, periodically require a certain amount of downtime for maintenance purposes. ESP's are often used in the control of particulates from basic oxygen steel-making furnaces, but no ESP's are currently in operation on domestic foundry EAF's.

3.5.4 Comparison of Particulate Removal Efficiency of Gas Cleaning Devices

Since virtually all foundry EAF's are controlled by fabric filters, there is a lack of performance data for scrubbers and ESP's. Particulate emissions from the EAF are predominately less than 1 micron in size and fabric filters are generally recognized as the most efficient collectors of submicron particulates.[8]

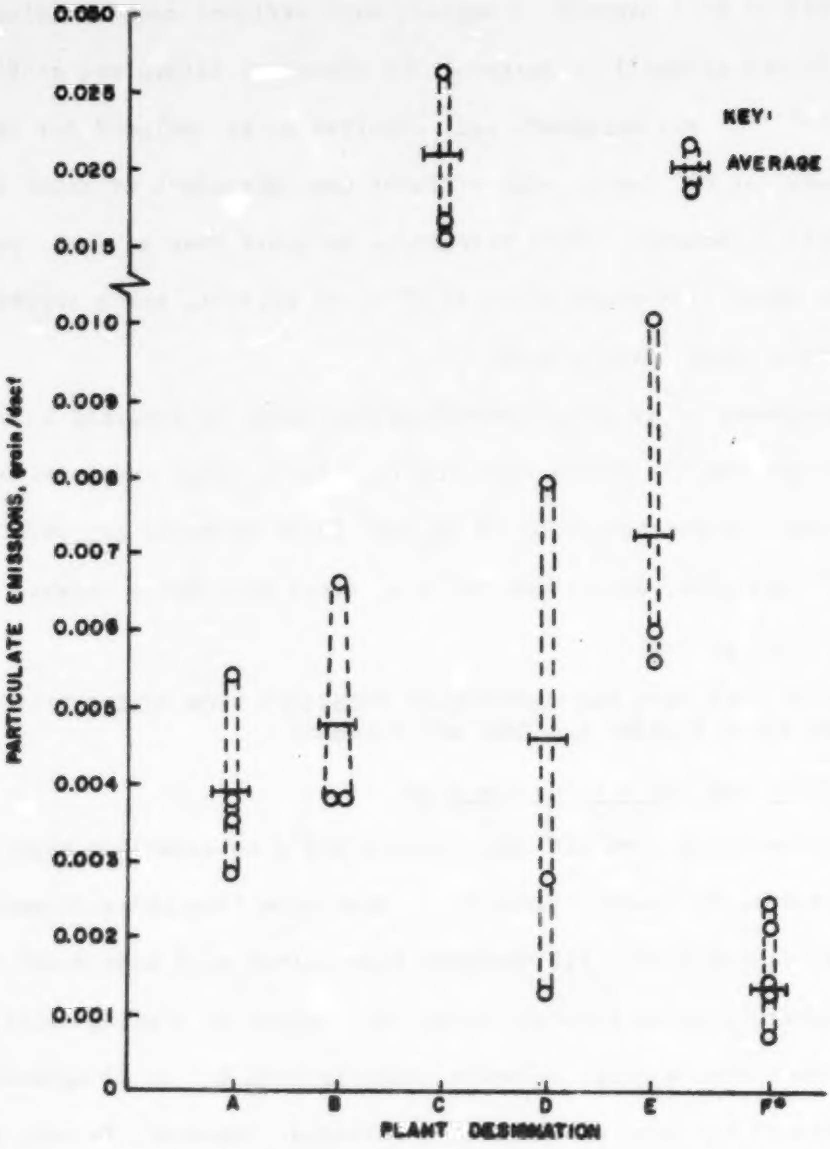
Based on EPA test data presented in Section 3.6 and standard emission factors, particulate removal efficiency for properly designed and operated fabric filters is 99.5 percent or better, with effluent concentrations of 12 mg/dsm^3 (0.005 gr/dscf) or better. The technical literature confirms this efficiency.[8,23,24] Wet scrubbers can, reportedly, be designed for 98 to 99 percent removal of EAF dusts, with effluent concentrations of about 46 mg/dsm^3 (0.02 gr/dscf).[8] However, other references indicate that scrubber performance on submicron dusts from steel mills is 95 to 98 percent, for a scrubber with a 60-inch pressure drop (fairly high).

ESP efficiency on submicron metallurgical dusts is reported by one reference as 95 percent.[24] Recent data reported for a large steel-making EAF showed effluent concentrations of 69 mg/dsm^3 (0.03 gr/dscf) are obtainable with ESP's,[25] and other data shows ESP's at steel mill EAF's capable of 6 mg/dsm^3 (0.0025 gr/dscf).

3.6 SUMMARY OF TEST DATA FOR PARTICULATE EMISSIONS FROM FABRIC FILTERS AT IRON AND STEEL FOUNDRY ELECTRIC ARC FURNACES

3.6.1 Test Data for EAF's Producing Iron

EPA obtained data from six iron foundry EAF's to establish typical levels of control capable by fabric filtration. Test data from these furnaces are summarized in Figure 3-15. All furnaces were fitted with side draft hoods, except at Foundry C which has roof hoods for control of melting emissions. Figure 3-15 indicates average emissions ranging from 8.7 to 23 mg/dsm^3 (0.0038 to 0.010 gr/dscf) for five of the tested furnaces. However, Furnace C showed average grain loadings of 48 mg/dsm^3. This is a foundry with a manually cleaned baghouse and carbon black injection to the furnace. A detailed summary of these test results appear in Appendix A-1.



*Not EPA Test Methods.

†grain/dscf x 2290 = mg/dsm^3

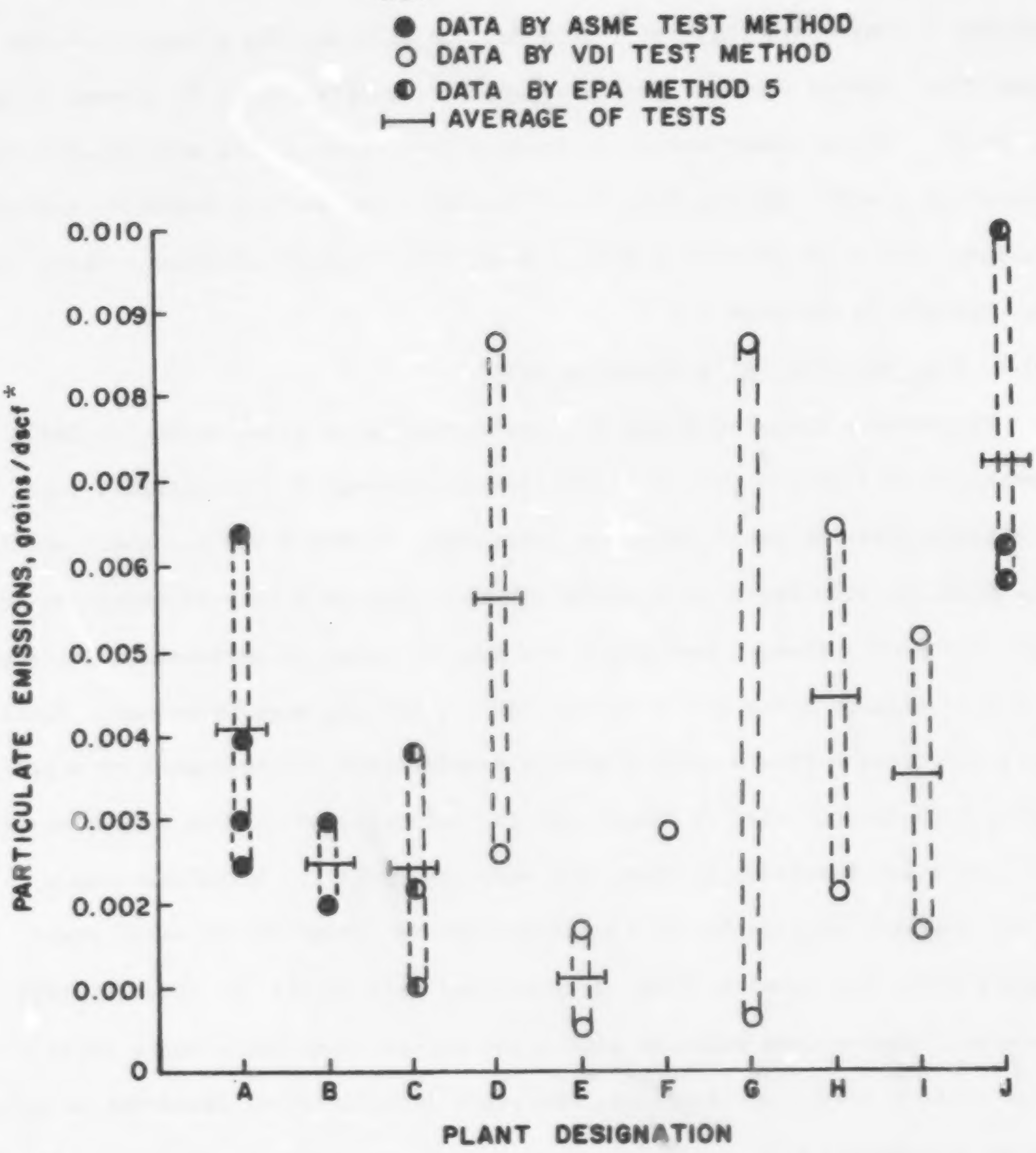
Figure 3-15. Summary of EPA Test Data for Baghouses on EAF's Producing Iron

Opacity readings were made on both the baghouse stack outlet and foundry roof monitors above the furnaces. Stack opacity generally ranged from 0 to 6 percent during melting with many of the readings showing 0 percent. Facility C, which had emission concentrations considerably greater than the other five, showed somewhat greater opacities, ranging up to 20 percent from the stack. Visual observations of foundry roof vents during melting also indicated an opacity ranging from 0 to 6 percent, but several foundries tested averaged only a few percent opacity. A detailed summary of these opacity data also appears in Appendix A-1.

3.6.2 Test Data for EAF's Producing Steel

Performance data for fabric filters operating on steel producing EAF's is summarized in Figure 3-16. Data for plants A through F were obtained from acceptance tests on newly installed baghouses. Plants A and B collect melting emissions via side draft hoods while plants C through F rely on direct evacuation roof taps. Plant G represents the typical level of performance for about 30 fabric filters installed on German EAF's producing steel castings. Plant H shows data from a French control device manufacturer for baghouses on steelmaking furnaces the size of those used in foundries. Data from well controlled EAF's at steel foundries in Italy are shown by Plant I. Emissions from a recent domestic application of the close capture design on two small steel foundry EAF's are shown by Plant J, the final data points.[14] This facility operates a shaker type baghouse with a low air-to-cloth ratio designed by a major control device manufacturer. Emission data for steel foundries is reported in Appendix A-2.

Opacity observations were also reported for several of these plants, and EPA personnel observed two of the plants. No visible emissions from the



*Grains/dscf x 2290 = mg/dsm^3

Figure 3-16. Summary of Reported Test Data for Baghouses on EAF's Producing Steel

baghouse were reported during normal operations, including oxygen lance periods. The maximum stack opacity reportedly seldom exceeds 5 percent during normal operating conditions. Opacity of baghouse exhaust at steel foundries is typically lower than for iron because carbon black added to iron is not completely absorbed by the melt. Five to 40 percent of carbon added to iron furnaces escapes in the furnace exhaust gas, and these extremely fine particles also pass through the baghouse. This tends to create a more opaque plume at iron foundries than at steel foundries.[1]

Maximum opacity reported from roof vents and monitors is 16 percent at one facility and 10 percent at another (6 minute average). These opacities are highest during tapping, because of alloy addition to the ladle. Charging generated substantially less visible emissions at the shop roof while backcharging emissions were between tapping and charging in magnitude. Because of the quantity of alloys added to the ladle and the hotter tap temperature, fugitives from a steel furnace are generally somewhat greater in magnitude than those from iron production. The opacity data for steel foundries is reported in Appendix A-3.

3.7 ACHIEVABLE LEVELS OF PARTICULATE CONTROL

Based on the preceding analysis of particulate control devices, the following control options were selected for further cost analysis in Section 4:

1. Control of melting emissions with side draft hoods (iron and small steel furnaces) or direct evacuation (steel) and fabric filtration.
2. Control of melting emissions with side draft hoods or direct evacuation with wet scrubbing.

3. Combination of item (1) and charging emission control by use of clean scrap (scrap preheaters or briquettes).
4 Control of charging and melting with close capture hoods as exemplified by the Hawley System, with fabric filtration.
5 Control of charging, melting and tapping with canopy hoods and side draft hoods (iron, small steel furnaces) or direct evacuation (larger steel furnaces).
6. Control of charging, melting, tapping and alloying with close capture hoods (Hawley) and an enclosed ladle pit with fabric filtration.

Total particulate removal efficiency of each control option is shown in Table 3-4. The efficiency ratings are based on the particulate removal efficiency of the control option under consideration, and emission factors developed in Section 2. The melting and refining emission factors for iron and steel production are 7.0 kg/Mg (14.0 lb/ton) charged and 8.0 kg/Mg (16.0 lb/ton) charged, respectively. Charging and tapping emissions for both iron and steel production are taken as an additional 10 percent of the melting emission factor, when a typical dirty charge is used. For the clean charge option, charging and tapping are considered to be 5 percent of total furnace emissions. This approach is probably somewhat conservative for estimation of charging and tapping emissions from iron production, since less alloying is normally conducted in the ladle, and tapping emissions from iron production are likely to be somewhat less than for steel. In preparing Table 3-4, baghouse effluent grain loadings were taken to be 12 mg/dsm^3 (0.0052 gr/dscf) and scrubber effluent loadings at 46 mg/dsm^3 at (0.02 gr/dscf).[8] Total particulate removal efficiency for side draft hoods fitted with baghouses,

TABLE 3-4. SUMMARY OF TOTAL PARTICULATE REMOVAL EFFICIENCIES FOR CONTROL OPTIONS AT IRON AND STEEL FOUNDRIES

	Emissions controlled			Total particulate removal (percent)[†]	
	Melting and refining	Charging	Tapping	Iron	Steel
Side draft hoods and baghouse[*]	X			87	89.5
Side draft hoods and scrubber[*]	X			87	89.5
Side draft hoods, preheater, baghouse	X	X		92	-
Side draft hoods, briquetter, baghouse	X	X		92	93
Close capture hoods, baghouse	X	X	X	96	93
Close capture hoods and ladle enclosure, baghouse	X	X	X	97.5	97.5
Side draft hoods, canopy hood,[*] baghouse	X	X	X	95	97

[*] Direct evacuation used for medium and large steel furnaces.

[†] Based on charging and tapping emissions equal to 10 percent of total melting and refining emissions.

compared to scrubbers, is shown to be equivalent. This reflects the fact that most of the emissions result from charging and tapping, which are not controlled. These uncollected emissions overshadow the fact that the fabric filter is a more efficient gas cleaning device than the scrubber.

The total furnace enclosure is not considered in this analysis because of a lack of data for evaluating control costs.

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4.0 COST ANALYSIS

4.1 INTRODUCTION

4.1.1 Control Options

This section presents cost estimates for several control options for reducing particulate emissions from electric arc furnaces (EAF's) at iron and steel foundries. Cost data were developed for emission control of charging, melting, tapping and alloying (steel foundries) during production of iron and steel. Cost data were prepared for new facilities and existing (retrofitted) plants.

Emission control technology is almost identical for iron and steel producing EAF's. Cost estimates were developed for the following fume collection systems and gas cleaning devices.

1. Control of melting emissions with side draft hoods (iron and small steel furnaces) or direct furnace evacuation (steel furnaces), and fabric filtration.
2. Control of melting emissions with side draft hoods or direct evacuation with wet scrubbing
3. Combination of item (1) and charging emission control by use of clean scrap (scrap preheaters or briquettes).
4. Control of charging, and melting with close capture hoods as exemplified by the Hawley System, with fabric filtration.
5. Control of charging, melting and tapping with canopy hoods and side draft hoods (iron and small steel furnaces) or direct evacuation (larger steel furnaces), with fabric filtration.
6. Control of charging, melting, tapping and alloying with close capture hoods and an enclosed ladle pit, with fabric filtration.

The total furnace enclosure is not evaluated because of the lack of data; however, capital costs appear somewhat greater than canopy hoods while operation costs should be low based on data from the only domestic enclosure in operation (See Section 3.3.3).

4.1.2 Model Plants

To illustrate costs of each emission control option, parameters which describe model, or typical EAF shops were developed for both gray iron and steel foundries. These parameters include typical furnace size, number of furnaces per shop and exhaust ventilation rates. Control costs are dependent on a variety of factors and often vary appreciably for installing similar equipment at different plants. Use of model plants is one method to establish typical control costs so the various control options can be compared on a common basis. These model plant parameters thus provide the basis for estimating capital costs and annual costs of operating emission control equipment.

Control costs are based on model plant parameters which were developed in Section 3 and shown here in Table 4-1. Two shop configurations are considered: (1) single furnace shops and (2) two furnace shops. Three furnace sizes are evaluated for each shop configuration. For the two-furnace shop, furnaces are assumed to be equal in capacity and symmetrical with respect to shop layout, although this does not always occur in actual practice.

Ventilation (exhaust) flow rates shown in Table 4-1 were used to size gas cleaning equipment (baghouses, scrubbers) required for each control option. For control of melting emissions, direct evacuation requires the minimum flowrate, but is applicable only to larger steel furnaces. Thus, side draft hoods are used for gray iron and small steel furnaces.

Costs for hoods, ductwork, supports, and other construction items for the close capture hoods and ladle pit enclosures were obtained from contacts in the industry. Operating hours shown in Table 4-1 are based on single 8-hour

TABLE 4-1. ENGINEERING PARAMETERS FOR MODEL FOUNDRIES PRODUCING IRON AND STEEL

	Single-furnace shop			Two-furnace shop		
	Small	Medium	Large	Small	Medium	Large
Plant capacity,						
megagram/hr	3.6	9.1	22.7	7.3	18.2	45.4
(tons/hr)	(4)	(10)	(25)	(8)	(20)	(50)
Ventilation, m^3/sec (acfm)						
a. Side draft evacuation, (Iron and small steel furnaces), and close capture/close capture-ladle pit	12.9 (27,400)	19.8 (42,000)	50.0 (106,000)	25.9 (54,800)	40.1 (85,000)	100 (212,000)
b. Direct evacuation - steel furnaces	-	7.0 (15,000)	16.5 (35,000)	-	14.1 (30,000)	33.0 (70,000)
c. Canopy hood and side draft evacuation (Iron and single furnace steel shops)	78.0 (165,000)	93.0 (197,000)	131 (278,000)	104 (219,800)	133* (282,000)	232* (491,000)
d. Canopy hood and direct evacuation (Medium and large, two-furnace steel shops)	-	-	-	-	107 (227,000)	164 (348,000)
Annual operating hours	1,600	1,920	2,800	1,600	1,920	2,800
Uncontrolled emission rate, kg/hr						
Iron	28	70	175	56	140	350
Steel	32	80	200	64	160	400

*Iron furnaces only; medium and large two-furnace steel shops controlled by option b, d.

Note: Data in Table is developed in Section 3, Emission Control Techniques.

shifts per day for all model plants. Small plants typically operate 200 days per year, medium plants, 240 days, and large plants, 350 days per year.

4.1.3 Capital Cost Estimates

Capital cost estimates reflect the cost of designing, purchasing, and installing a particular capture system and control device. These estimates include costs for both major and auxiliary equipment, rearrangement or removal of existing equipment, site preparation, equipment installation, and design engineering. Estimates do not account for production lost during equipment installation or start-up. Lost production can sometimes be recovered by overtime work or rescheduling vacation periods. Information for capital costs was developed through contacts with foundry operators, equipment vendors, design engineering firms, EPA contractor studies[1,2,3] and EPA in-house files. Capital costs reflect first quarter 1977 costs.

4.1.4 Annualized Costs

Annualized cost estimates include operating costs (labor, maintenance and utilities) and capital charges (depreciation, interest, administrative overhead, property taxes, and insurance). Operating cost estimates were based on EPA contractor studies and contacts with vendors. The cost of electricity is assessed at 4 cents per kilowatt-hour.[4] Maintenace and bag replacement costs for baghouses and maintenance costs for scrubbers were determined from a cost estimation manual developed for EPA.[3] These maintenace costs are 1 percent of installed cost for baghouses and 4.4 percent of installed costs for scrubbers. The major capital charges - depreciation and interest - were determined by EPA based on the capital recovery factor, an interest rate of 10 percent, and an equipment life of 10 years. Capital costs also include 4 percent of installed cost to account for administrative overhead, property taxes, and insurance.

4.2 CONTROL COSTS FOR FURNACES PRODUCING IRON

4.2.1 Annualized Costs

Total annualized costs for each emission control option for existing (retrofitted) and new EAF's producing iron are summarized in Table 4-2 for single and two furnace shops of various melt capacity. Approximate particulate removal efficiency of each control option is also indicated. Costs include installed capital costs amortized for 10 percent over 10 years, operating and maintenance costs, and miscellaneous capital charges as described above. Detailed cost breakdowns for each shop configuration are given in Appendix B.

The side draft hood included in all control options captures particulate emissions from melting only. Options for controlling charging emissions are use of clean scrap by preheating or briquetting, installing a canopy hood, or installing an annular hood located just above the furnace cover, illustrated by the close capture concept. Tapping emissions are controlled by the canopy hood, or by encompassing the ladle with a close capture hood, or an enclosed ladle pit.

Control costs were first determined for model new facilities. Capital costs for side draft evacuation and canopy/side draft evacuation systems are based on the cost estimation manual developed for EPA,[3] and information from the Industrial Gas Cleaning Institute.[2] Costs for the close capture system are based on data obtained from the Hawley Engineering Company.[5] Sources of cost data for the preheater and the briquetter were studies by Battelle Columbus Laboratories[1] and Combustion Engineering,[6] respectively. Costs for the ladle pit enclosure are based on data obtained from Armco Steel Company.[7]

Costs for existing model facilities were developed by scaling up new source costs with the appropriate retrofit factors. Retrofit factors apply

Table 4-2. SUMMARY OF TOTAL ANNUALIZED CONTROL COSTS FOR MODEL EXISTING FOUNDRIES PRODUCING IRON CASTINGS, IN THOUSANDS OF DOLLARS PER YEAR[*]

Control option:		Side draft hoods	Side draft hoods	Side draft hoods, preheater	Side draft hoods, briquetter	Close capture hoods	Close capture hoods, ladle enclosure	Canopy and side draft hoods
Gas cleaning device:		Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse	Baghouse
Total particulate control efficiency, percent[†]		87	87	92	92	96	97.5	95
Single-furnace shops[‡]								
3.6 Mg/hr	Existing shops	43	151	66	94	54	66	309
	New shops	43	141	66	94	50	58	246
9.1 Mg/hr	Existing shops	70	206	103	206	86	106	340
	New shops	70	195	103	206	80	94	272
22.7 Mg/hr	Existing shops	168	439	254	482	207	233	509
	New shops	168	419	254	482	192	220	399
Two-furnace shops								
7.3 Mg/hr	Existing shops	88	235	123	162	110	134	374
	New shops	88	221	123	162	102	119	288
18.2 Mg/hr	Existing shops	130	328	195	401	162	196	461
	New shops	130	311	195	401	150	173	369
45.4 Mg/hr	Existing shops	311	727	484	942	381	458	806
	New shops	311	703	484	942	356	408	655

[*] Data summarized from detailed cost analysis in Appendix B which shows capital and operating costs for both new and retrofitted (existing) facilities.

[†] For this analysis, charging and tapping emissions are considered to be 10 percent of total melting emissions which reflects alloy addition to the ladle.

[‡] Total melt capacity, Mg/hr (megagram/hr) = 1.10 ton/hr.

only to evacuation systems that would incur spatial restrictions when installed in existing plants. This applies specifically to installing canopy hoods which might require numerous changes in the building; the Hawley system, which may require some space to freely swing the annular ring hood; and the ladle enclosure, which would require construction of a pit or rearrangement of existing foundry equipment. The retrofit factor for canopy hood installations was taken as 33 percent, based on a study of building evacuation systems for EAF's in the iron and steel industry.[8] Retrofit factors of 10 percent and 15 percent were applied, respectively, to the close capture/enclosed ladle pit system. The latter two retrofit factors are considered best judgment for retrofit installations at this time. They are based on a contingency allowance used in standard engineering practice to cover items of an uncertain nature. A normal assumption for contingency allowance is 10 to 15 percent of capital investment.

Table 4-2 indicates annual emission control costs ranging from $43,000 for side draft hoods on small, existing furnaces to $942,000 for side draft hoods and a briquetter for two large furnaces. To obtain overall control efficiency in the range of 92 to 96 percent, the least cost option is the close capture hoods for any sized shop. For the highest level of control, 97.5 percent, close capture hoods plus ladle enclosures are shown considerably less costly than the canopy-side draft hood combination.

4.2.2 Comparison of Installed Capital Cost Estimates with Actual Data

Because only limited cost data are currently available from actual installations, the above analysis was used to develop cost estimates. Data obtained by EPA for installed costs of canopy hood and close capture systems is summarized in Table 4-3 along with estimates derived by the cost analysis. The discrepancies between the actual and estimated costs emphasise the basic fact

Table 4-3. SUMMARY OF REPORTED CAPITAL COSTS COMPARED TO EPA ESTIMATES OF TOTAL INSTALLED COSTS*

	Capital cost reported by facility ($)	Total installed costs, based on EPA analysis ($)
Retrofitted canopy hood, 215 m^3/s (457,000 afcm)	1,950,000[3]	-
Retrofitted canopy hood, 231 m^3/s (491,000 afcm)	-	1,984,000
Retrofitted canopy hood, 89 m^3/s (190,000 afcm)	805,000[10]	-
Retrofitted canopy hood, 93 m^3/s (197,000 afcm)	-	1,610,000
New close capture hoods, 10 m^3/s (22,500 afcm)	125,000[11]	-
New close capture hoods, 13 m^3/s (27,400 afcm)	-	236,000
Retrofitted close capture hoods, 20 m^3/s (42,000 afcm)	250,000[12]	-
Retrofitted close capture hoods, 20 m^3/s (42,000 afcm)	-	370,000

*Costs updated to 1976 levels by appropriate cost index.

that emission control costs can vary widely between individual foundries. Actual installed costs as reported by various facilities often do not include labor supplied by plant personnel and capital charges such as taxes and insurance; these costs are included in the EPA cost estimates.

4.2.3 Cost-Effectiveness of Control Options for Furnaces Producing Iron

This section provides a graphical analysis of cost-effectiveness of alternate control options for retrofit of model two-furnace shops. Annualized cost per kilogram of particulate removal is plotted versus plant capacity for three selected control options. The options are indicative of three discrete levels of pollutant removal efficiency which comprise the range of control capability for gray iron EAF's:

- Control of melting emissions only by side draft evacuation with an 87 percent efficiency.
- Control of melting and charging emissions with a close capture system at 96 percent efficiency.
- Control of melting, charging, and tapping emissions with the close capture/ladle pit enclosure combination system at 97.5 percent efficiency.

These control options represent least expensive options for the given level of efficiency. This criteria eliminates consideration of the canopy hood system, the clean scrap option, and wet scrubbers.

The curves developed to show cost effectiveness of three control options are shown in Figure 4-1. For the smallest (7.3 megagram per hour) plant, the cost per kilogram removed ranges from $1.09 for control of melting emissions (low efficiency) to $1.49 per kilogram for controlling melting, tapping, and charging emissions (high efficiency). For the 18.2 megagram per hour plant control costs fall sharply to $0.54 and $0.72 per kilogram removed for the low and high removal levels, respectively.

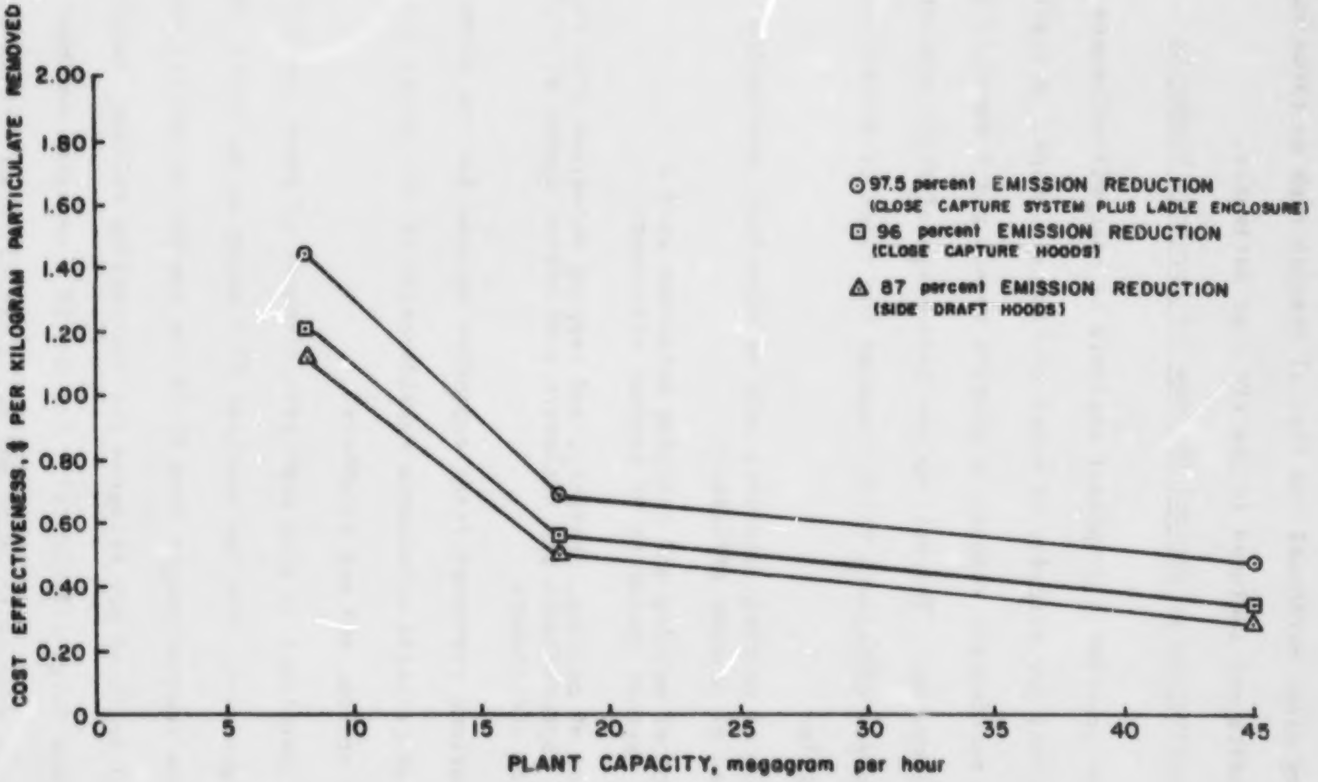

Figure 4-1. Cost Effectiveness of Alternative Control Options for Retrofitted Iron Producing Furnaces (Two-Furnace Shops).

There is an anomaly between single-furnace and two-furnace shops of approximate equal melt capacity which points out the effect of one variable, shop configuration, on control costs. Control costs for the two-furnace shop of a 7.3 megagram per hour melt capacity are roughly 100 percent greater than for the single-furnace shop of a 9.1 megagram per hour capacity. Clearly, economies of scale can be very important when considering control costs for various shop configurations.

4.3 CONTROL COSTS FOR FURNACES PRODUCING STEEL

4.3.1. Annualized Costs

Total annualized costs for each emission control option for existing (retrofitted) and new EAF's producing steel are summarized in Table 4-4 for single- and two-furnace shops of various melt capacity. Approximate particulate removal efficiency of each control option is also indicated. Costs include installed capital costs amortized for 10 percent over 10 years, operating and maintenance costs and miscellaneous capital charges as described previously in the Introduction subsection 4.1.4. Detailed cost breakdown for each shop configuration are given in Appendix C. Model plant parameters for each shop configuration were also outlined in the introduction of this section.

Ventilation flow rates for melting control of medium and large steel furnaces are lower than for gray iron furnaces because larger steel furnaces can be evacuated directly through a fourth hole cut into the furnace shell. Direct shell evacuation can be used for steel furnaces of 9.1 megagram per hour or greater without jeopardizing the metallurgy involved in producing steel. However, direct shell evacuation cannot generally be used in gray iron furnaces as it tends to reduce carbon content in the melt.

Table 4-4. SUMMARY OF TOTAL ANNUALIZED CONTROL COSTS FOR MODEL EXISTING FOUNDRIES PRODUCING STEEL CASTINGS, IN THOUSANDS OF DOLLARS PER YEAR*

Control option:		Direct evacuation	Direct evacuation	Direct evacuation clean scrap (briquettes)	Close capture system	Close capture system plus ladle enclosure	Canopy and direct evacuation
Gas cleaning device:		Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse
Total particulate control efficiency, percent		89.5	89.5	93	93	97.5	97
Single-furnace shops†							
3.6 Mg/hr	Existing shops	43‡	151‡	94‡	54	66	309
	New shops	43	141	94	49	58	246
9.1 Mg/hr	Existing shops	28	106	164	86	106	374
	New shops	28	99	164	80	94	288
22.7 Mg/hr	Existing shops	61	198	372	207	223	510
	New shops	61	188	372	192	220	399
Two-furnace shop							
7.3 Mg/hr	Existing shops	88‡	235‡	162‡	110	134	374
	New shops	88	221	162	102	119	288
18.2 Mg/hr	Existing shops	52	163	324	162	196	386
	New shops	52	154	324	150	173	308
45.4 Mg/hr	Existing shops	115	321	747	382	458	596
	New shops	115	306	747	356	408	483

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*Data summarized from a detailed cost analysis in Appendix C which shows capital and operating costs for both new and retrofitted (existing) facilities.

†Total melt capacity; Mg/hr (megagram/hr) = 1.10 ton/hr.

‡Costs for side draft hoods, not direct evacuation; direct evacuation not feasible for the small furnace size.

When combining canopy hood exhaust with direct shell evacuation, total flow rates are noticeably reduced only for the two-furnace configuration. The reduction in ventilation resulting from direct shell evacuation is not substantial enough to offset the canopy hood exhaust requirements on single-furnace shops.

Side draft hoods or direct shell evacuation, included in all control options, capture particulate emissions from melting only. Emissions from charging (and back-charging) are controlled by using clean scrap, a canopy hood, or an annular hood located immediately above the furnace such as the close capture system. Emissions from tapping and alloying in the ladle are controlled by enclosing the ladle with a local hood or an enclosed pit, with evacuation to a control device. Use of clean scrap does not substantially reduce emissions from back-charging and thus only the briquetter is considered for analysis of steel foundries.

Table 4-4 indicates annual emission control costs ranging from $28,000 for direct evacuation of a medium furnace to $747,000 for direct evacuation with scrap pretreatment on large furnaces. To obtain an overall control efficiency of 93 percent, the least cost option is the close capture system for all furnace sizes. For a 97 percent level of control, close capture hoods with a ladle enclosure are less costly than canopy hoods combined with direct evacuation.

The methods and basis for developing these cost estimates are analogous to those used for gray iron furnaces. Costs are nearly identical to those for gray iron, with the exception of medium and large furnaces with melting control by direct evacuation. In this case, exhaust flow rates are lower than for side draft hoods, and thus, capital and operating costs are reduced.

Costs for canopy hood systems in existing model facilities were developed by scaling up new source costs in exactly the same manner as was done for gray iron foundries. Retrofit costs for the close-capture system and the ladle pit enclosure were developed by taking the actual dollar differences between new and existing gray iron plants and transferring them to plants similar in configuration and capacity for steel foundry production. Developing retrofit costs for these two particular systems was done this way to be consistent with previous assumptions.

Another difference between gray iron and steel furnaces is the particulate removal efficiencies. Removal efficiencies for steel foundries are generally 1 or 2 percent greater than for the respective iron foundries.

4.3.2 Cost Effectiveness of Control Options for Furnaces Producing Steel

This section provides a graphical analysis of the cost effectiveness of alternate control options for retrofit of two-furnace shops. Annualized cost per kilogram of particulate removal is plotted versus plant capacity for three selected control options. These options are indicative of three discrete levels of pollutant removal efficiency which comprise the range of control capability for steel producing EAF's:

- Control of melting emissions only by side draft or direct shell evacuation at 89 percent efficiency.
- Control of melting and charging emissions with a close capture system at 93 percent efficiency.
- Control of melting, charging, and tapping emissions with the close capture and ladle pit enclosure system at 97 percent efficiency.

These control options considered in this presentation represent the least expensive options for the given level of efficiency. This criteria eliminates consideration of the canopy hood system, the clean scrap option, and wet scrubbers.

Curves developed to show cost effectiveness of three control options are shown in Figure 4-2. For the smallest two-furnace shop (7.3 megagram per hour) plant, the cost per kilogram removed ranges from $1.06 for control of melting emissions (low efficiency) to $1.49 per kilogram removed for controlling melting, tapping, and charging emissions (high efficiency). These costs are nearly identical to those for an equivalent size iron EAF. For the 18.2 megagram per hour plant, costs drop sharply to $0.21 per kilogram removed for control of melting (low efficiency) emissions and $0.73 for total furnace control by close capture hoods/ladle enclosures (high efficiency). For the large, 45.4 megagram plant, costs range from $0.13 for control of melting only (low efficiency) to $0.46 for close capture/ladle enclosure (high efficiency). Costs for high efficiency control of steel furnaces are comparable to high efficiency control of iron furnaces. However, for low efficiency control (melting only), costs are about 50 percent less for steel furnaces than iron furnaces because of lower gas volumes from the direct evacuation system used on steel furnaces.

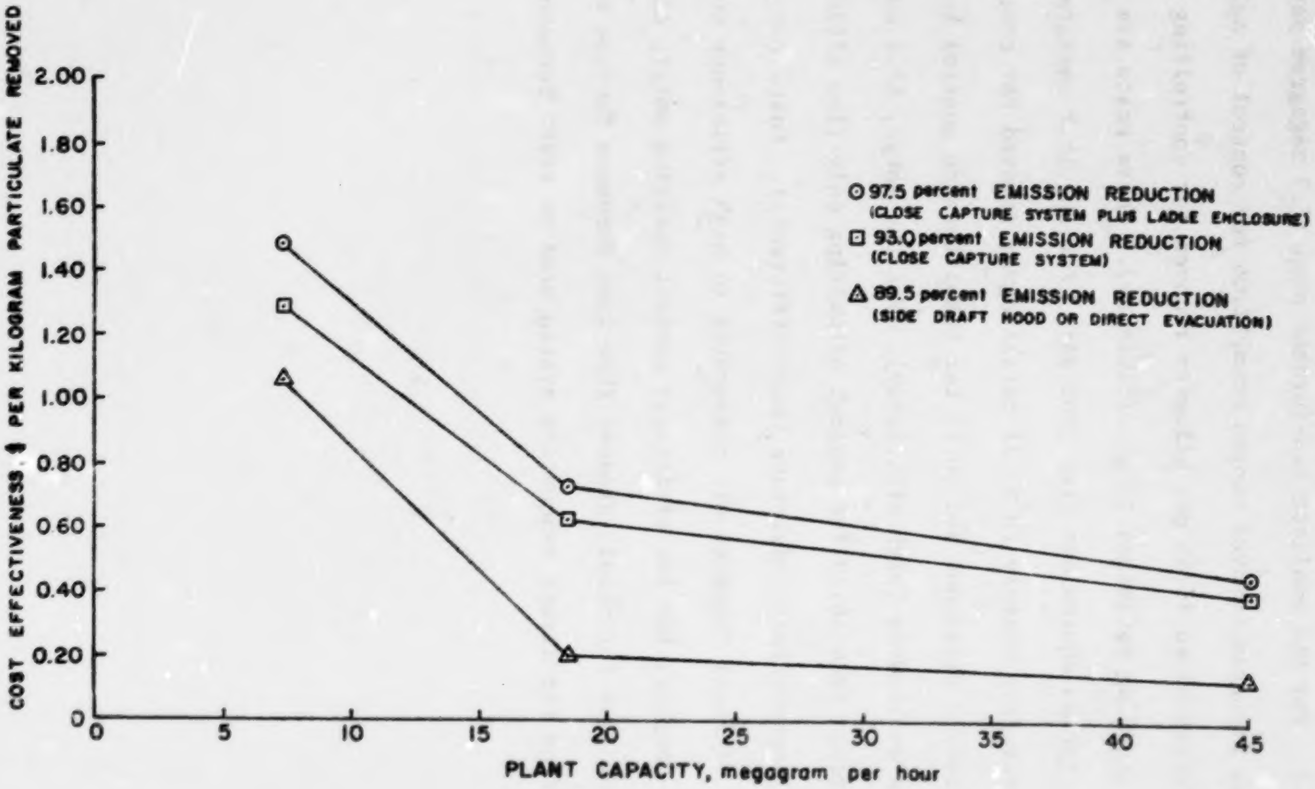

Figure 4-2. Cost Effectiveness of Alternative Control Options for Retrofitted Steel Producing Furnaces (Two-Furnace Shop).

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5.0 ENVIRONMENTAL IMPACTS OF APPLYING CONTROL TECHNOLOGY

5.1 IMPACT ON PARTICULATE EMISSIONS FROM THE IRON AND STEEL FOUNDRY INDUSTRY

Table 5-1 summarizes estimates of total annual emissions from ferrous foundries for three levels of control. Annual emission totals were based on the annual production of castings from EAF's in ferrous foundries (about 4 million tons annually), and by averaging emission factors and control efficiencies for iron and steel foundries presented in Section 3. It was necessary to average these values because the exact level of iron production compared to steel production is unknown. Most ferrous foundries control melting and refining emissions with side draft hoods (or equivalent) and baghouses, but provide little or no control of charging and tapping emissions. Total annual emissions for ferrous foundries are estimated at about 10,000 Mg, or 11,020 short tons, as shown in Table 5-1. Control of charging and tapping by canopy hoods would reduce annual emissions to about 1,800 Mg per year, while retrofitting close capture systems and ladle pit enclosures would result in annual emissions of about 1,150 Mg. Retrofitting all existing furnaces with the furnace enclosure would result in annual emissions of 460 Mg, a substantial 96 percent reduction from current levels.

5.2 SUMMARY OF ENERGY REQUIREMENTS

Table 5-2 shows electricity consumption of air pollution control equipment relative to electricity required for melting for single furnace model plants. A review of recent foundry installations indicates roughly five horsepower per

Table 5-1. SUMMARY OF TOTAL PARTICULATE EMISSIONS FROM IRON AND STEEL FOUNDRY EAF'S FOR VARIOUS CONTROL OPTIONS

Level of control	Total particulate removal efficiency* (percent)	Total annual emissions (Mg/yr)
Current situation: control of melting and refining only		10,000
Improved control: melting, refining, charging, tapping		
By canopy and side draft hoods	96	1,800
By close capture system and ladle pit enclosure	97.5	1,150
By complete furnace enclosure	99	460

*Average efficiency for iron and steel furnaces.

Table 5-2. ENERGY REQUIREMENTS, IN MILLION kWh PER YEAR, FOR MELTING COMPARED TO EMISSION CONTROL OPTIONS FOR MODEL PLANTS

	Total particulate removal* (percent)	Furnace size		
		Small 3.6 Mg/hr	Medium 9.1 Mg/hr	Large 22.7 Mg/hr
Melting and refining	-	3.2	9.6	35
Direct evacuation	89.5	-	0.10	0.23
Side draft hoods	88	0.16	0.30	1.10
Close capture system	93	0.16	0.30	1.10
Close capture system plus ladle pit enclosure	97.5	0.16	0.30	1.10
Side draft plus canopy hood†	95	0.30	0.54	1.40
Direct evacuation plus canopy hood	97	-	0.34	0.53

*Average of iron and steel furnace removal efficiency.

†Canopy hood operation for 15 percent of furnace operational time.

thousand cfm of exhaust flow is required by fans in a typical hood collector-baghouse control system. The electric arc furnace (EAF) typically consumes about 500 kWh of electricity per ton melted in the foundry. Three control options require equivalent exhaust flowrates, and thus, have comparable energy requirements. Electrical energy required to operate side draft hoods, close capture systems and close capture/ladle pit enclosure is approximately 3 to 5 percent of energy used in melting and refining, for each furnace size. Energy requirements for the side draft/canopy hood combination, however, are much greater, even though total particulate control efficiency is lower than two of the less energy intensive options. A side draft/canopy hood on the small furnace will use about 10 percent as much energy used in melting. For the large furnace with side draft/canopy hoods, about 5 percent of energy used in melting is necessary to operate control devices.

5.3 GENERATION AND DISPOSAL OF FURNACE DUST

5.3.1 Quantities of Dust Generated

Virtually all electric arc furnaces in ferrous foundries use baghouses for collecting particulates from furnaces exhaust gas. An approximation of total dust collected per year can be established based on emission factors; tonnage of iron produced and baghouse efficiency, as developed in Sections 2 and 3. Electric arc furnace production capacity is about 3.6 million megagrams (Mg) annually of finished castings and furnace utilization rate for 1976 was 73 percent of capacity. At an average emission rate of 8.3 kg/Mg (including charging and tapping) for iron and steel foundries, and a typical particulate removal efficiency of about 88 percent, total collected dust for 1976 is calculated at about 28,000 megagrams (31,000 tons).

Table 5-3 shows the quantities of dust requiring disposal which would be collected by model foundries with existing control technology and also with improved control of charging and tapping. Small foundries typically handle about 38 megagrams/yr while large foundries must dispose of about 420 megagrams/yr. With improved control of charging and tapping emissions at model plants, the quantities of collected dust would increase by only 10 percent, as shown in Table 5-3.

5.3.2 Dust Handling

Improper handling and disposal of particulates collected from the EAF can easily cause some entrainment of dust to the atmosphere. Current state and federal regulations generally do not address this problem because the importance of fugitive emission sources has only recently drawn much attention. While this is not a major problem, methods are available to minimize entrainment problems.

Dust collected from the foundry is usually placed in landfills. Economic recycling of these iron-bearing dusts has not been demonstrated. The most effective method for handling dust is a pelletizing operation which practically eliminates entrainment problems. However, many foundries will probably continue to handle loose dust, usually transporting it by truck to the disposal site. Open bodied trucks should have a cover to place over the load, and vehicle speed should be limited to avoid losses during transport. Alternatively, dust from the baghouses (or ESP's) can be emptied into sealed bags or containers which would also serve to contain dusts at the disposal site. Still another option is to produce a slurry by injecting water at some point of the dust handling system.

TABLE 5-3. QUANTITY OF DUST COLLECTED AT MODEL FOUNDRIES IN MEGAGRAMS PER YEAR

	Total particulate* control efficiency, percent	Furnace size		
		Small, 3.6 Mg/hr	Medium 9.1 Mg/hr	Large 22.7 Mg/hr
Melting and refining by side draft hoods	88	38	115	420
Melting, refining, charging, tapping by close capture system and ladle pit enclosure	97.5	42	128	465

*Control efficiencies averaged for iron and steel foundries.

5.3.3 Pelletizing

Many foundries and steel mills are currently pelletizing collected furnace dusts to facilitate efficient disposal. Dusts collected from the EAF are fine in size and can easily be wetted and rolled into granular pellets. This eliminates potential for dust reentrainment and improves ease of dust handling. The most common pelletizer configurations are the inclined disk and cone-shaped units. The units are fairly small and can often be installed such that pellets fall directly into a truck. Dust free transfer from baghouse to pelletizer can be accomplished with enclosed tank-type trucks or conveying through enclosed transfer pipes.

5.3.4 Recyling Potential for Electric Arc Furnace Dust

Dusts collected from foundry EAF's contain significant amounts of iron oxides, but there are currently no commercial processes for recovering this material. Recycling and material recovery from steelmaking dusts is under investigation in this country and abroad. A major technical problem in ferrous recovery is contaminating elements, notably lead and zinc, which may be present in high concentrations. Zinc and lead can damage the interior of a furnace, and also contaminate the melt. Recovery of valuable zinc is one option under investigation.[1]

Metal recovery from furnace dusts is technically feasible, but several problems are restricting use of available technology:

- There is no single process available for recycling all types of furnace residues at a single processing facility.
- Most plants do not produce large enough quantities of residues in one location to make investment in such facilities feasible.

5.3.5 Landfill Disposal

Dust collected from the EAF can be safely landfilled if appropriate precautions are taken. Care in disposal is necessary because, as shown in Table 5-4, relatively high levels of trace elements including the toxic metals lead, cadmium, and arsenic, are often present in foundry dust.[2]

Trace elements shown in Table 5-4 are present in EAF dusts as metal oxides which are insoluble in pure water. However, most are slightly soluble in acidic solutions and rainfall over many parts of the country is somewhat acidic. Further, since little control can be exercised over the possibility of chemical reactions occurring in the landfill, landfill site design must preclude horizontal or vertical migration of these metals to surface or groundwaters. The Safe Drinking Water Act of 1974 provides for protection of potential drinking water supplies, and sets limits on concentration of certain toxic metals. Where geo-hydrological conditions do not provide reasonable protection against leaching of these elements, precautions such as impervious liners should be taken to insure long-term protection of the environment.

TABLE 5-4. TRACE METALLIC COMPONENTS OF BAGHOUSE HOPPER DUST (ppm)[2]

Pb - 10,000	Ti - 300	As - 100	Be - 1
Cu - 8,000	Li - 300	B - 50	
Zn - 5,000	Cr - 200	V - 50	
Na - 3,000	Zr - 200	Co - 50	
Ni - 1,500	Ba - 200	Sb - 50	
K - 5,000	Mo - 150	Sr - 30	
Sn - 300	Cd - 100	Ag - 10	

Disposal sites often require approval by the responsible state agency to ensure that sites are environmentally sound. This will become more common as states comply with the Resource Conservation and Recovery Act of 1976 which specifically addresses disposal of solid and potentially hazardous wastes.

When disposal is to a municipal landfill, dust must be segregated from municipal refuse. As organic matter decomposes, acidic conditions develop and could dissolve portions of trace metals in the dust, developing potential for leachate contamination of nearby waters.

Several features can be designed into a landfill to ensure safe disposal of wastes, mitigating potential for contamination of ground and surface waters and the atmosphere. General criteria to be considered are:

- Location away from excessive slopes and flood-plains. Location in areas of low population, low land value and low ground-water contamination potential.
- No hydraulic or subsurface connection should exist with standing or flowing surface or ground waters.
- The base of the landfill should be located a sufficient distance above the high water table to prevent leachate movement to aquifers. Use of clay or plastic liners may be necessary.
- Diversion ditches should be constructed around the site to intercept surface waters, thus reducing infiltration and runoff from the site.
- Dusts should be covered daily with earthfill and compacted to avoid reintroduction into the atmosphere, and reduce infiltration of rainwater.

If an electrostatic precipitator (ESP) was used to control furnace emissions, dust would be collected in a dry form and disposal considerations discussed above for baghouse-collected dusts would also apply to the ESP-collected dusts.

5.4 DISPOSAL OF SCRUBBER WASTEWATER AND SLUDGE

Wet scrubbers are generally not used in the United States for control of EAF furnace emissions from foundries. In fact, a review of the Penton Publishing Company's 1974 listing of iron foundries shows fabric filters were used exclusively.[3] In situations where scrubbers could be used, scrubber wastewater should be contained in a settling pond and recirculated. Protection of groundwaters and surface waters is essential, and landfill disposal requirements of dry dusts also apply here.

5.5 EFFECT OF EMISSION CONTROL ON PLANT NOISE

Noise control is rapidly gaining attention due to OSHA regulations for in-plant personnel exposure and EPA restrictions on permissible noise levels at the plant boundry. Fans which power baghouses or other control devices are one noise source at the foundry. Proper design and installation of fans can significantly reduce noise levels from these sources. However, it is much easier to design a quiet fan than to retrofit an existing noisy fan for noise reduction. Inclusion of the following equipment and design parameters have been suggested to significantly dampen external fan noise.[4,5]

- Fan silencer
- Fan casing heavy enough to reduce transmission of noise
- Seals between casing and rotating shaft that do not allow escape of fan's internal noise
- Expansion joints acoustically treated and designed to be as far removed from the fan as feasible
- Duct walls to and from the fan heavy enough or acoustically treated to retain fan noise
- Fan mounted on appropriate vibration damping pads
- If necessary, a vibration analysis should be conducted, considering radial and thrust vibration amplitudes, dynamic balance, foundation resonance, and so on.

While fan noise can be substantial if not properly controlled, such noise is often insignificant compared to furnace noise which is radiated to the surrounding countryside. Noise from a large electric arc furnace during meltdown is caused by electrode arcing, and is directly proportional to the area of small furnace openings. Fortunately, effective control of air pollution from the furnace dictates closing of most openings in the furnace, and this tends to reduce noise escaping the furnace shell. Openings which should be investigated both as a noise source and an air pollution source are:

- Slag door
- Fourth hole slip joint
- Roof ring gap
- Electrode holes

Air pollution control significantly reduces furnace noise if a furnace enclosure is used. Here, the entire furnace is enclosed, isolating the furnace from the melt shop and creating a barrier to furnace noise.

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6.0 COMPLIANCE TEST METHODS AND MONITORING TECHNIQUES

This section discusses sampling and monitoring methods which are applicable to both new and existing sources.

6.1 MEASURING PARTICULATE EMISSIONS

6.1.1 Standard Approach - EPA Reference Method 5

For gray iron and steel foundries using the electric arc furnace (EAF), particulate emissions can normally be measured using EPA Method 5, and visible emissions can be determined with Method 9. Both of these reference methods should be conducted in accordance with the provisions in Appendix A of 40 CFR, Part 60. When sampling a positive pressure baghouse with no distinct exhaust stack, special provisions must be included as described in the next section.

When sampling high efficiency control devices such as the fabric filters typically used on foundries, a relatively small amount of particulate is captured by the Method 5 sampling filters because of low mass concentrations in the exhaust stream. Accurate recovery of the sample from the sampling train and weighing of the recovered samples requires collection of at least 50 mg of particulate to insure an accuracy of ± 10 percent. Thus, EPA suggests that a minimum volume of 9.0 dsm^3 (320 dscf) be drawn through the sampling train when Method 5 is applied to foundries.[1] Sampling trains which collect large sample volumes and conform to Method 5 specifications, are commercially available. Depending on the sampling train selected, a reduction in sampling time and thus the cost of testing can often be realized.

6.1.2 Special Techniques for Positive Pressure Baghouses

A positive pressure type baghouse is often favored over the negative pressure type for new installations on EAF's because of significantly lower installation costs and ease of identifying and replacing broken bags. However, unlike negative pressure (pull-through) baghouses, positive pressure systems do not ordinarily have distinct exhaust stacks. Rather, the positive pressure baghouse often discharges cleaned gas through a series of louvers, vents or short, "stub" stacks located above each compartment. Consequently, these systems cannot always be sampled in strict accordance with criteria of EPA Method 5 which were developed to measure emissions from a single stack.

EPA requires operators of positive pressure baghouses at source categories that are subject to new source performance standards to develop sampling procedures for demonstrating compliance. If sampling procedures acceptable to EPA cannot be developed, exhaust gases must be collected from each compartment, and directed to a single stack which can then be sampled by Method 5. To avoid this procedure, EPA and others have recommended modifications to Method 5 which should allow development of an acceptable sampling procedure.[1,2]

Since positive pressure baghouses discharge to the atmosphere through multiple compartments and vents, sampling each discharge point would be costly and time-consuming. If each compartment is in equivalent condition, with similar operating parameters, an acceptable procedure is to sample a randomly selected, representative number of compartments or subareas. The representative selection of compartment(s) can be based on analysis of baghouse design and estimation of air flow distribution through the baghouse.

Standard Method 5 equipment has been used with pressurized baghouses when the systems discharge through short, stub stacks. Because of the low effluent mass concentrations resulting from high efficiency baghouses, the duration of the sampling period is usually extended to about 3 hours to collect enough mass for the sample filters. To estimate emissions, individual points may be sampled by traversing or by simultaneous sampling at several points. Measurement of flow velocity through stubstacks can ordinarily be accomplished by standard equipment.

Without stub stacks, a problem often encountered in using Method 5 for positive pressure baghouses is the inability of standard sampling equipment to measure low exhaust velocities (about 2 m/s) encountered in the roof monitor exhaust vents. Method 5 requires isokinetic sampling, that is, maintaining air velocities drawn through the sampling probe equal to the velocity of the exhaust stream, to assure representative collection of particles. Since Method 5 sampling equipment cannot measure low flow rates, isokinetic sampling cannot be maintained.

One acceptable solution to this problem is to measure the average flow rate prior to sampling, using instruments capable of low velocity measurements. The Method 5 sampling equipment can then be preset to sample at this flow rate. This average sampling rate can then be used for the duration of the sampling period.

Another alternative is to sample emissions at subisokinetic rates, which involves withdrawing the sample with Method 5 equipment at a rate lower than the exhaust stream velocity. EPA data has indicated that for particles with aerodynamic diameters less than 5 microns, typical of EAF dusts, and for sampling of low velocity streams, an insignificant error should result when the isokinetic requirements of Method 5 are not observed. Under these conditions any errors that do occur result in a positive bias.

While Method 5 has been used with some success on pressure baghouses, several state agencies have developed sampling procedures using hi-vol samplers.[3-5] The hi-vols are used to measure concentrations within several compartments or may be drawn across a horizontal cross-section of roof monitors or exhaust vents. Inherent limitations on the accuracy of this method have not been quantified, but it is believed that judicious use of hi-vols can give a reasonable estimate of emissions.

6.2 VISIBLE EMISSION MONITORS

Visible emission monitors are based on a light source and receiver (transmissometer) installed in the exhaust stack of the air pollution control device. Output from the monitor is ordinarily connected to a pen recorder which provides a continuous record of relative opacity of the exhaust gas. Thus, an increase in recorded opacity indicates a decrease in performance of the emission control device. Performance standards for monitors have been promulgated by EPA and are published in the Federal Register, October 6, 1975. (Appendix B of 40 CFR Part 60).

Continuous monitors can be installed in the exhaust stack of negative pressure (pull-through) baghouses. However, some of the newer baghouses installed on EAF's are the positive pressure type which have no distinct stack, but discharge through a series of vents or short stacks above each individual compartment. For this type of baghouse, continuous monitoring can be accomplished by either:

- internal monitoring of several representative compartments with conventional, continuous monitors, or
- use of recently developed instruments capable of monitoring long distances to measure opacity over the length of several compartments, or over the top of the baghouse, immediately above the discharge vents.

However, such devices are fairly costly to install and maintain, and requirements for continuous monitors should be carefully evaluated.

6.3 VISIBLE EMISSIONS FROM FOUNDRY ROOF MONITORS

At foundries where charging and tapping are poorly controlled, fugitive emissions generally escape to the atmosphere through vents in the roof, called "monitors". Emissions from roof monitors cannot be measured with transmissometers because such emissions are not uniform and vary widely in duration and magnitude. Many foundries have a number of monitors or roof fans through which fugitive emissions from the furnace may escape. Evaluation of roof monitor emissions not amenable to continuous monitoring devices must therefore be conducted by trained smoke observers, in accordance with EPA Reference Method 9.

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7.0 ENFORCEMENT ASPECTS

7.1 INTRODUCTION

This section summarizes the type of data required to enforce various types of standards applicable to iron and steel foundries. Basically, there are four types of formats in which standards can be written:

- Limits on concentration of pollutants emitted
- Mass limits
- Opacity limits
- Equipment specifications and operating practices

7.2 CONCENTRATION LIMITS

Concentration limits on exhaust gas, commonly expressed as grains/dry standard cubic foot or mg/dry cubic meter, are used widely. Enforcement requires the use of a field sampling crew and field testing equipment which is expensive and time consuming. In the case of particulate sampling, the method required is EPA Reference Method 5. In using Method 5, difficulties can arise from the low flow rates which accompany large area discharges typical of positive pressure baghouses which are often installed on new foundries. This often hinders isokinetic sampling which can cause errors in sample collection. In some cases EPA has required new sources to provide a stack or well-defined exit to positive pressure baghouse such that emissions can be properly measured by Reference Method 5. Although there are currently no standard procedures for measuring emissions from positive pressure baghouses, several EPA publications address procedures which have been used.[1,2]

These involve construction of a "quasi stack" and also procedures to measure emissions from roof monitors of positive pressure baghouses. Because concentration limits also imply the presence of a well-defined exit stack or duct for emissions which are not available in many foundries, concentration limits are often difficult to define.

One disadvantage of concentration limits is that they do not account for lower mass emissions which would result from systems with lower flow rates. That is, since the total mass emitted is the product of concentration and flow rate, systems which minimize exhaust flow rate, while meeting a concentration standard, will have lower total emissions than systems not minimizing flows. A concentration standard does not recognize benefits of minimizing exhaust flow rates. An advantage to concentration limits, however, is that they can be inexpensively screened using opacity observations. The correlation between opacity and mass concentration can be used to indicate situations where more detailed testing is required.

7.3 MASS LIMITS

Emission standards may also be based on the maximum mass of emissions relative to either production rate (kg particulate/Mg of metal produced) or furnace capacity (kg particulate/Mg of metal charged). The units for these two methods differ, since the production rate is affected by the operating conditions (length of heat), while the furnace capacity is independent of this factor.

The data required to enforce a mass standard would still require a field test to measure the mass of emitted particulates. These measurements are analogous to those for concentration standards.

Required process information is the furnace capacity and the times when a cycle starts and ends (which can easily be obtained from plant logs). The capacity of a single furnace is determined by averaging the tons of steel produced for all cycles which contribute to the particulate sample obtained during a performance test.

7.4 OPACITY LIMITS

Particulate emissions can also be regulated solely in terms of opacity limits, as is currently done with baghouses in most states. Opacity regulations can be readily enforced using EPA smoke inspectors trained in accordance with Reference Method 9. Difficulties sometimes arise, however, because of plume thickness. Continuous opacity monitors are now available to record control device performance, and can provide help in enforcing opacity standards.

In some cases, it may be difficult for a specific plant to meet an opacity regulation because of conditions or problems peculiar to that specific plant. In this case, EPA may grant or establish an opacity standard for the particular plant, with approval of the EPA Administrator.[3]

7.5 EQUIPMENT STANDARDS

Standards could also be written in a form that specifies the type of control equipment to be used. For instance, a standard might be set for EAF's which required foundries to install and operate a control system consisting of a canopy hood in combination with direct furnace evacuation. However, a problem arises here with determining whether a proposed piece of control equipment will, in fact, provide adequate emission control. This potential problem is well illustrated by the canopy hood. Proper design depends entirely on the specific foundry and the physical configuration of the foundry roof, wall openings, cross-drafts, etc. It is usually difficult to predict collection efficiency of such a canopy, and in certain shops, the canopy may only provide very low collection of fume.

Monitoring a standard of this type is easy, and in practice, this seems to be the type of standard that many local pollution control agencies actually apply to existing facilities. Inspectors generally check to see that the baghouses and evacuation systems are installed and functioning properly.

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3. Code of Federal Regulations, 40, Part 60. Standards of Performance for New Stationary Sources, Subpart A. General Provisions, Paragraph 60.11. Compliance with Standards and Maintenance Requirements, Subparagraph e2. July 1, 1977.

8.0 REGULATORY OPTIONS FOR CONTROL OF ELECTRIC ARC FURNACES AT IRON AND STEEL FOUNDRIES

8.1 SUMMARY OF CONTROL TECHNOLOGY OPTIONS FOR IRON AND STEEL FURNACES

There are essentially three levels of control which one can attain for the electric arc furnace: control of melting only; control of melting and charging; and control of melting, charging and tapping. Summarized below are the preferred technologies for meeting these three levels of control; the ranges of costs and control efficiencies; the energy requirements; and the quantity of solid waste generated. The implications of each control option with respect to formats for writing emission regulations are also discussed.

8.1.1. Control of Melting Emissions Only

Melting (and refining) emissions account for about 90 percent of total emissions from the EAF, with charging and tapping accounting for the remainder. Side draft hoods and fabric filtration are currently the most common technique for controlling melting emissions at iron and smaller steel foundries. For larger steel furnaces, direct shell evacuation can be used, which reduces both the flowrate required to evacuate the furnace and the size of the accompanying fabric filter unit.

8.1.1.1 Control of Iron Furnaces - Side Draft Hoods Plus Fabric Filter

Side draft hoods typically collect 90 to 99 percent of melting and refining emissions; usually the dust-laden air stream is cleaned in a fabric filter. A well-designed side draft hood can collect about 99 percent of melting and refining emissions, resulting in a net control of 87 percent of total furnace emissions as discussed in Section 3.7. (Charging and tapping, which account for 10 percent of total emissions, are not controlled by side draft hoods.) Energy to operate side draft exhaust fans ranges from 3 to 5 percent of total energy required for melting scrap in the large- and small-sized model plants, respectively, as indicated on page 5-2. Quantity of dust collected by the fabric filter ranges from 38 megagrams annually for the small (3.6 Mg/hr) furnace to about 420 megagrams annually for the large (22.7 Mg/hr) furnace. Total annual costs (capital charges and operation cost) for the side draft hood plus baghouse system for new iron furnaces range from $43,000 for one small 3.6 Mg/hr furnace to $168,000 for a large 22.7 Mg/hr furnace (see Section 4). Retrofitting side-draft hoods on iron furnaces normally presents few problems, and the annual cost for retrofitted side-draft hoods is generally equal to that encountered in new installations. (This control option also applies to small steel furnaces as they cannot use the direct evacuation systems described below.)

8.1.1.2 Control of Steel Furnaces: Direct Evacuation Plus Fabric Filter

Melting emissions from medium- and large-sized steel furnaces can be effectively controlled by a direct evacuation roof tap which requires only about 25 percent of the exhaust flow rate used by side draft hoods. The reduced flow rate results in smaller-sized duct work and a smaller baghouse, thus reducing control costs. For the medium (9.1 Mg/hr) and large (22.7 Mg/hr) steel furnaces, annual control costs are $28,000 and $61,000, respectively, which are less than one-half the costs of side draft hoods for the same furnaces. Retrofit costs for direct evacuation plus a baghouse are normally equal to costs of new installations. This control option cannot, however, be applied to iron furnaces as the chemistry of the iron bath is adversely affected by direct evacuation. Small steel furnaces also cannot use direct evacuation for melting emission control because of difficulties in precisely controlling exhaust flow rate.

Capture efficiency for direct evacuation is equal to side draft hoods; i.e., 90 to 99 percent of melting and refining emissions. The quality of dust collected by the baghouse may be slightly greater for the steel furnace, compared to iron because emissions are slightly greater. Energy requirements for operating direct evacuation systems are about one-third of those for side draft hoods because of reduced exhaust volume.

8.1.1.3 Regulatory Formats for Control of Melting Emissions

A regulation for control of melting emissions of the EAF must first ensure that fumes are properly evacuated at the furnace, then secondly ensure that efficient gas cleaning is accomplished. Regulatory options are (1) mass or concentration limits for the outlet of a gas cleaning device (which requires sampling of emissions), (2) opacity limits (which do not require sampling), and (3) an equipment specification (which also does not require sampling).

Effective capture of furnace emissions by side draft hoods, or direct evacuation relies on maintaining an adequate exhaust flowrate through the furnace evacuation system. With the fabric filter gas cleaning device, outlet particulate concentrations tend to be insensitive to the inlet concentration. Because of this characteristic, a greater exhaust flowrate (i.e., side draft hoods) will result in greater net mass emissions even though the mass concentration is low. A mass emission standard, therefore, must be chosen to provide the operator with enough flexibility to maintain high enough exhaust flowrates for good capture of furnace emissions. A concentration standard would provide this flexibility. Baghouses can typically reduce furnace exhaust concentrations to 12.0 mg/dsm^3, as indicated in Section 3.6. An opacity standard, in addition, would be effective for evaluating baghouse performance since a well-designed and operated baghouse should exhibit an opacity of zero or only a few percent. For melting emissions which are controlled by side draft hoods and baghouse, EPA test data presented in Section 3.6 and Appendix A shows that maximum opacity at the baghouse stack is normally less than 10 percent for iron furnaces and normally less than 5 percent for steel. There may be exceptions to these norms during injection of carbon black at iron foundries, and in extreme cases, during oxygen lancing at steel foundries. An opacity standard could also be applied to fugitive emissions escaping the fume collectors, except that supporting data is not generally available for setting such a standard.

An equipment standard can also be adapted for controlling melting emissions since control technology is well developed and accepted by the industry. An equipment standard should specify type of equipment (e.g., side draft hoods for iron or steel, or direct evacuation for steel) and design parameters necessary to ensure effective particulate evacuation and removals. For example, an equipment standard might specify baghouse parameters such as air-to-cloth ratio (which is normally low, 2 or 3 to 1) as well as the flowrates necessary for effective particle capture. Exhaust flowrates summarized on page 4-3 are used by newer foundries. These flowrates are on the order of 100 percent greater than those used by some older evacuation systems (refer to Section 3.6 and Appendix A which summarizes test data from furnaces). Flowrates lower than those shown on page 4-3 can still provide effective evacuation of melting emissions. Higher flows are more common today mainly in response to OSHA requirements.

8.1.2 CONTROL OF MELTING AND CHARGING

Together, melting and charging emissions account for about 90 percent of particulate emissions from the EAF. The most practical options for controlling these emissions are the side draft hood (direct evacuation in the case of steel) plus use of clean scrap, and the close capture hood systems; in both cases, a baghouse is used for gas cleaning.

8.1.2.1 Control of Melting and Charging at Iron Furnaces

Of the two options for controlling melting and charging emissions from iron foundries, the close capture hoods are most efficient, providing total particulate removals of 96 percent. (It should be noted that this estimate is based on limited data, see page 3-29.) The side draft hood combined with scrap cleaning using a preheater will control about 92 percent of total furnace emissions (refer to page 3-53). In terms of annual costs, close capture hoods are somewhat less expensive. For a new small model plant (3.6 Mg/hr), the annualized cost for close capture hoods is $50,000 compared to $66,000 for the side draft/preheater option. For a new large model plant (22.7 Mg/hr), close capture hoods and side draft/preheater annual costs are $192,000 and $254,000, respectively (refer to Section 4). Retrofitting a preheater may be difficult due to structural limitations. This is also true for close capture hoods, where costs of a retrofit may be substantially increased above costs for new installations. Fuel availability (usually natural gas) can also be a problem. As mentioned earlier in Section 3, the use of a charge preheater may reduce net melting energy requirements by about 15 percent. Both control options use about the same energy for control of melting, and only a small additional amount is used by the close capture design for charging control. Collected dust quantity is almost identical to that collected by systems discussed above in Section 8.1.1 since charging emissions represent only an additional 5 percent of total furnace emissions. When establishing a regulation for melting and charging, it must be recognized that controlled charging emissions will usually be difficult to distinguish from melting emissions due to their intermittent nature. It would, therefore, be difficult to establish and enforce a mass or concentration standard for charging emissions. An opacity standard could be applied to charging emissions from a control device only for systems with one baghouse per operating furnace. The opacity standard would, however, be applicable to emissions which escaped collection by the close capture hoods, and especially applicable to emissions from charging of preheated scrap. For uncontrolled charging emissions which escape foundry roof vents, EPA data (see Appendix A and Section 3.6) indicates maximum opacities are typically 10 percent for 3 minutes. However, it will sometimes be difficult to distinguish charging emissions from other foundry emissions escaping through the same roof vent. Use of an equipment standard would avoid problems with enforcing mass or concentration standards. However, retrofit of close capture hoods or even preheaters for charging control may often be limited because of space restrictions. These problems will be of minor importance for new foundries.

An equipment standard for melting and charging control should specify certain items. For close capture hoods, the necessary exhaust flowrate, (12.9 m^3/sec for a 3.6 Mg/hr furnace, ranging to 50 m^3/sec for 22.7 Mg/hr furnace, see page 4-3), method of diversion of exhaust to charging hoods and actual size or shape of hoods should be specified (see Section 3.3.4). For the preheater option, control of emissions can be addressed by specifying evacuation to an afterburner or specifying the use of preheaters with built-in secondary combustion chambers.

8.1.2.2 Control of Melting and Charging at Steel Foundries

Control options for melting and charging at steel foundries differ from those discussed above for iron foundries only in that direct evacuation is substituted for side draft hoods for medium- and large-sized furnaces. Total particulate removal efficiency for preheaters combined with direct evacuation and a baghouse is about 93 percent (refer to page 3-53), a level also achievable by close capture hoods installed on steel furnaces. Annualized costs for close capture hoods at steel foundries are the same as those discussed above for iron. Sometimes a briquetter is used at steel foundries instead of a preheater; costs are still greater than for close capture hoods, even though gas volumes are reduced with direct evacuation. Annualized costs for direct evacuation/briquetter are about $93,000 and $372,000, respectively, for the small and large model foundries while close capture costs are about $49,000 and $192,000, respectively. As in the case of iron foundries, the cost of retrofitting these control options may be substantially increased if extensive structural modifications must be made. In terms of energy consumption, direct evacuation only requires about 1 percent of energy used for furnace operation - less than energy requirements of side draft hoods on iron foundries; energy use by the briquetter is not available. Generation of collected dusts will be about 5 percent greater than dust generation with melting control only.

Comments relative to the format of emission standards presented in Sections 8.1.1.3 and 8.1.2.1 also apply here, except that for uncontrolled charging emissions which escape through foundry roof vents, EPA test data in Appendix A shows maximum opacities are typically 20 percent for 3 minutes for steel (compared with 10 percent for 3 minutes with iron).

8.1.3 Control of Melting, Charging and Tapping

The last level of control includes tapping as well as melting and charging emissions. Tapping emissions account for an estimated 5 percent of total furnace emissions. Three basic techniques for total control of melting, charging and tapping emissions were identified in Section 3 as:

- Canopy hoods coupled with side draft hoods (iron) or direct evacuation (steel).
- Total furnace enclosure.
- Close capture hoods with a ladle pit enclosure.

In all of the above cases, a baghouse is usually used for gas cleaning.

8.1.3.1 Control of Melting, Charging and Tapping at Iron Foundries

Of the three control options, canopy hoods have been employed at foundries which currently control charging and tapping. The close capture/ladle pit enclosure system has not been used to date at foundries. However, several foundries use close capture hoods, and a patented ladle pit enclosure is operating at a large steel-making EAF. The total furnace enclosure concept is in operation at only one domestic steel-making EAF facility and has not been used in iron foundries to date.

Canopy hoods combined with side draft hoods typically provide 95 percent removal of all furnace emissions, while the close capture hood/ladle enclosure system is somewhat more efficient at 97.5 percent. Total enclosure systems are expected to be at least as efficient as the close capture hood/ladle enclosure system, if not more so (refer to Section 3.7). Canopy hood efficiency is adversely affected by crossdrafts in the shop and may, in some cases, provide substantially less than the 80 percent collection of charging and tapping emissions. Collection efficiency of the close capture/ladle enclosure is not subject to this problem, although the 80 percent efficiency claimed by the manufacturer for collecting charging emissions could be reduced when very dirty scrap is used. Adequate data is not available for a proper assessment.

When comparing costs and energy requirements for the close capture/ladle enclosure and side draft/canopy hood options, the canopy hood appears in an unfavorable light. For a small (new) model furnace, annualized costs for close capture/ladle enclosures are $58,000 compared to $246,000 for the side draft/ canopy hoods. For the large model furnace, the canopy hood option is 100 percent more costly than for the close capture/ladle enclosure. Costs of retrofitting the close capture/ladle enclosure system are approximately 5 to 10 percent greater than costs of a new installation. For the canopy hood option, however, retrofit costs are approximately 30 percent greater than new installations (see Section 4.0). Energy requirements, as presented in Section 5.0, are about 100 percent greater for the canopy hood option than for close capture/ ladle enclosures with respect to the small model furnace, and about 30 percent greater for the large model furnace.

Annualized costs and energy requirements for the total furnace enclosure have not been assessed due to the lack of operating data. However, capital costs are expected to be greater for the enclosure compared to other options, while operating costs (including energy requirements) should be between those estimated for close capture/ladle enclosures and side draft/canopy hoods.

The quantity of dust collected by each of the above three options would be approximately equal, corresponding to the uncontrolled emission factor for iron production (7.0 kg/Mg of iron charged for melting and refining emissions and 0.7 kg/Mg for charging and tapping).

Regulatory formats based on concentration or mass standards could be applied to effluents from the baghouse which cleans the combined charging, tapping and melting emissions. It would be difficult, if not impossible to set a standard specifically for charging and/or tapping because of the difficulty in identifying and measuring these specific emissions at the baghouse. An opacity standard would be useful to ensure proper baghouse operation, and particularly useful in evaluating fugitive emissions which escape collection by the furnace evacuation systems. EPA visible emission data for uncontrolled tapping emissions which escape foundry roof vents, as presented in Section 3.6 and Appendix A, show that opacity is normally less than 20 percent for 3 minutes, with no alloys added to the ladle, and normally less than 40 percent for 3 minutes with alloy addition to the ladle.

An equipment standard specifying either close capture/ladle enclosures or total furnace enclosure could be used for new shops which could be designed to accommodate these devices. For retrofitted shops, space and furnace operational characteristics will usually preclude retrofit of the total enclosure. Space limitations at some foundries may also hinder installation of the close capture/ladle enclosure design. Installation of canopy hoods are not usually subject to as severe space limitations, although foundry roof areas must sometimes be extensively modified.

An equipment standard should specify the design parameters which affect particulate collection efficiency. For example, efficiency of the canopy hoods depends on the size of the hood, distance between the hood and the furnace, relative diameter and thermal uplift of the furnace, and presence of cross drafts in the shop. Since each foundry is different, it would be difficult to quantitatively specify these parameters in an equipment standard for canopy hoods. Exhaust ventilation rates, however, have a significant impact on canopy efficiency and typical flowrates are summarized on page 4-3. For the close capture/ladle enclosure design for control of melting, charging, and tapping, the equipment specification should contain the items already discussed in Section 8.1.2.1, namely exhaust flowrates (page 4-3), diversion of flow to charging hood of ladle enclosure, and perhaps, geometric design of the hoods.

8.1.3.2 Control of Melting, Charging and Tapping at Steel Foundries

The above discussion (8.1.3.1) pertaining to the iron foundries also applies to steel foundries with minor exceptions as noted below.

The close capture/ladle enclosure and total furnace enclosure options are identical for iron and steel foundries, the only difference being a somewhat greater quantity of dust collected for steel (emission factors are 7.0 kg/Mg of iron and 8.0 kg/Mg of steel, plus 10 percent for charging and tapping). Annualized costs for canopy hoods/direct evacuation system at medium and large steel furnaces are slightly lower than canopy hoods/side draft hoods on iron furnaces because of reduced gas volumes necessary for control of melting emissions with direct evacuation. Similarly, energy requirements are slightly lower for this option at steel foundries. Costs and energy use of the canopy hoods themselves are equal for iron and steel furnaces.

Comments in Section 8.1.3.1 concerning regulatory formats for total control of iron furnaces also apply to these options identified for steel foundries. The only difference would be those aspects concerning use of direct evacuation for melting control at steel furnaces, relative to side draft hoods used for melting control at iron furnaces. These aspects were discussed in Section 8.1.1 which discusses control of melting emissions only.

8.2 FORMAT OF REGULATIONS FOR THE ELECTRIC ARC FURNACE AT IRON AND STEEL FOUNDRIES

Regulations may be based on one of four available formats:

- mass limitations (kg/hour of particulate, or kg/Mg of iron or steel produced)
- concentration limitations (usually mg/dry standard cubic meter - mg/dsm^3)

- opacity limitations
- equipment specifications requiring the installation and proper operation of certain types of control equipment.

Mass discharge standards commonly used in state regulations for processes such as the EAF expressly limit total mass of particulate discharged, based on process weight rates. However, many New Source Performance Standards (NSPS) promulgated by EPA for other industries are written in terms of exhaust concentration achievable by best demonstrated control technology and do not directly limit total mass discharge. In practice, opacity standards are often used by state regulatory agencies as a major enforcement tool, because violations can be easily and quickly determined. This is generally true of both furnace emission stacks and fugitive emissions from charging and tapping. Equipment standards are not usually written into a regulation, but are often implied, as stringent regulations can often be met only with certain types of control equipment. Each of the above regulatory formats is applicable to the EAF and has certain advantages and disadvantages which influence the effectiveness of reducing particulate emissions and also enforcement of the standard.

8.2.1 Concentration Limitations

A concentration limitation is often applied to baghouses which tend to be insensitive to inlet concentrations and produce a fairly consistent effluent concentration. This type of standard is desirable as it does not restrict volume of air withdrawn through furnace evacuation systems, allowing flexibility in capture flow rates maintained at the furnace. However, concentration limits do not restrict the total mass discharged from the baghouse.

The concentration standard (and also mass standards) cannot generally be applied to just charging and tapping, since these emissions are intermittent and of a short duration. Accurate sampling of collected and controlled charging and tapping emissions is almost impossible, and it may also be difficult to identify charging and tapping emissions from other furnace operations.

Enforcing a concentration standard requires sampling of control device exhaust streams which is sometimes difficult. Sampling procedures are not standardized for the positive pressure baghouse, sometimes installed on EAF's, because of multiple discharge points and low exhaust flow rates. Measuring low exhaust concentrations from the very efficient fabric filter requires long sampling times to ensure collection of adequate sample weight. Sampling procedures, in general, must also consider the variation of fume concentration during furnace operation cycles. However, enforcement of concentration standards can frequently be supplemented by opacity readings because of the general relationship between concentration and visible emissions from the EAF. A properly designed and well operated baghouse is capable of an effluent concentration of 12 mg/dsm^3 (0.0052 gr/dscf) based on EPA test data summarized in Section 3.6.

8.2.2 Mass Standards

Unlike a concentration standard, a mass discharge standard limits the total amount of particulate emitted from the baghouse. Stringent mass standards may provide an incentive to an operator to restrict air flow through the fume control equipment to the minimum necessary for effective capture of furnace emissions to maintain compliance. This is often an undesirable situation because reduced exhaust flow can result in inefficient fume capture at the furnace, increasing uncontrolled fugitive emissions. Consequently, a stringent mass discharge standard must be designed to allow the furnace operator flexibility in maintaining an exhaust flow rate most effective for a particular shop.

Enforcing a mass standard requires sampling which involves difficulties in measuring low exhaust concentrations, analogous to sampling for concentration. Unlike concentration standards, mass standards are based on plant production rates which must be accurately obtained from the plant.

8.2.3 Opacity Standards for Melting and Charging and Tapping Emissions

Opacity standards can be enforced quite easily and frequently by trained smoke observers, and this is a strong advantage compared to concentration or mass limits which require actual sampling of emissions. An opacity standard is the only type which can be used to evaluate fugitive emissions which result from a poorly operating melting, charging or tapping evacuation system. This is an important advantage because a furnace evacuation system could be collecting only a small portion of furnace emissions, while still meeting mass emission standards as measured as the outlet of the fabric filter glass cleaning device.

Another advantage of an opacity standard is that it could be written to allow for the higher emission rate which occurs immediately after charging and during alloying. However, enforcement may present problems. If opacity is read outside the foundry above roof vents, charging emissions may be undistinguishable from other fugitive shop emissions escaping through the same roof vent. The opacity standard could be written to be applicable to emissions as they leave the furnace, prior to exiting through roof monitors. This, however, may cause enforcement problems, as such emissions to the internal foundry atmosphere are not normally considered within the realm of air pollution.

One common criticism of an opacity standard is the somewhat subjective nature of smoke reading. However, a properly operating baghouse should exhibit an opacity of zero, or only a few percent. It is thus fairly easy to observe whether the control system is functioning properly.

Opacity standards alone are not generally considered to be quantitative enough to evaluate performance of a sophisticated and highly efficient control system. However, they have several important features which account for their frequent use by state agencies. Enforcement is easy since violations are easily recorded by one trained observer in a short amount of time. Determining compliance does not require advance notification and preparation at the plant, and compliance can often be determined from outside plant grounds. Thus, both costs and manpower requirements are drastically lower for enforcing opacity standards compared to concentration and mass standards. EPA visible emission data for several foundries was reported in Section 3.6 and Appendix A. For baghouse emissions, the maximum opacity generally reported for iron furnaces is below 10 percent, and for steel furnaces, below 5 percent. For fugitive emissions escaping foundry roof vents, charging of iron furnaces generally showed maximum roof vent opacities below 10 percent, for 3 minutes. While tapping iron, with no alloys added to the ladle, maximum opacities were below 20 percent for 3 minutes. For steel furnaces, data developed from large steel mill EAF's showed charging emissions below 20 percent (3 minutes) and tapping emissions below 40 percent (for 3 minutes) at the roof monitor.

8.2.4 Equipment Standards for Melting Emissions

To avoid difficulties inherent with sampling emissions, regulations could simply require installation of specific control equipment. An equipment standard must be written in a manner which avoids potential retrofit problems. For example, structural or operational constraints may prohibit use of certain control techniques. An example would be lack of physical space around a furnace for a close-capture hood or furnace enclosure.

Enforcement of an equipment standard for melting emissions would be quite easy as the standard would specify the required type of control. The design and types of melting control systems are well established, and level of performance achievable is quite clear. Certain parameters must be included in the equipment standard, as discussed in this section and in Section 3.0. The regulatory agency would, however, need to evaluate engineering plans for a proposed control device and determine whether the design is adequate. This may place a burden on some agencies.

8.3 SUMMARY OF REGULATORY CONTROL OPTIONS

Table 8-1 summarizes control options for new medium-sized (9.1 Mg/hr) model iron furnaces and indicates particulate removal efficiency, total annualized costs and energy requirements, as developed in preceding sections. Table 8-2 summarizes control options and other data for new steel furnaces (9.1 Mg/hr). For retrofitted furnaces, annual costs tend to increase slightly (see Section 4.0) while particulate removal efficiency and energy requirements are equal to new installations. For small and large model plants, total particulate efficiency is equal to that shown in the tables for medium plants, while annual emissions change in proportion to furnace size and annual operating time. Total annualized costs and energy requirements for other furnace sizes increase or decrease from those shown for medium furnaces, roughly in proportion to the relative furnace sizes (see Section 4.0).

As shown in Tables 8-1 and 8-2, control of melting emission provides 87 to 89 percent control of total furnace emissions; this can be achieved by side draft hoods or direct evacuation plus baghouses. This results in annual emissions of 16.1 megagrams for steel and 17.5 megagrams for iron furnaces. Energy requirements and costs are substantially less for the direct evacuation system, but this can only be used on steel furnaces.

Table 8-1. SUMMARY OF REGULATORY OPTIONS FOR A NEW MODEL 9.1 Mg/hr FURNACE PRODUCING IRON

Control option	Total particulate removal efficiency (percent)	Annualized[*] costs for new plants (10^3 $/yr)	Energy requirement (10^6 kWh/yr)	Annual emissions (Mg/yr)
Melting Emissions				
1. Side draft hood plus baghouse	87	70	0.30	17.5
Melting and Charging				
1. Side draft hood plus clean scrap plus baghouse	92	103	0.30[†]	10.7
2. Close capture system plus baghouse	96	80	0.30	5.4
Melting, Charging and Tapping				
1. Side draft and canopy hoods plus baghouse	95	272	0.54	6.7
2. Close capture system, ladle pit enclosure plus baghouse	97	94	0.30	3.4
3. Total furnace enclosure plus baghouse	99	N/A	N/A	1.3

[*] Annualized costs include amortized capital costs, operation costs and maintenance cost.

[†] Does not account for potential savings in melting energy requirements resulting from charging of hot scrap.

Table 8-2. SUMMARY OF REGULATORY OPTIONS FOR A NEW, MODEL 9.1 Mg/hr, FURNACE PRODUCING STEEL

Control option	Total particulate removal efficiency (percent)	Annualized[*] costs for new plants (10^3 \$/yr)	Energy requirement 10^6 kWh/yr)	Annual emissions (Mg/yr)
Melting Emissions				
1. Direct evacuation plus baghouse	89	28	0.10	16.1
Melting and Charging				
1. Direct evacuation plus clean scrap plus baghouse	93	61	0.11[†]	10.8
2. Close capture system plus baghouse	93	80	0.30	10.8
Melting, Charging and Tapping				
1. Direct evacuation plus canopy hoods plus baghouse	97	288	0.36	4.6
2. Close capture system plus ladle pit enclosure	97	94	0.30	3.8
3. Total furnace enclosure	99	N/A	N/A	1.5

[*] Annualized costs include amortized capital costs, operation costs and maintenance costs.

[†] Does not account for potential energy savings resulting from charging of hot scrap.

For control of melting and charging, either the close capture system can be used (for both iron and steel) or scrap preheaters in conjunction with side draft hoods (iron) or direct evacuation (steel). For iron furnaces, the close capture system is less expensive than preheaters with side draft hoods, and also provides improved collection of all furnace emissions (96 percent versus 92 percent for side draft hoods with preheater). For steel furnaces, however, the preheater with direct evacuation is less expensive than close capture hoods because exhaust flows from direct evacuation are considerably less than for close capture hoods.

For control of melting, charging and tapping, data is only available for two options: (i) canopy hoods with side draft hoods (iron) or direct evacuation (steel) and (ii) close capture hoods with ladle pit enclosure. The close capture/ladle enclosure system is more efficient (97.5 percent total particulate removal, versus 95 percent for the canopy hood option) and also less costly to operate, by a factor of three or four.

The total furnace enclosure is probably more efficient in particulate reduction potential, but data for assessing this option is not readily available. Capital and operation costs are likely to be greater for the enclosure than the close capture option, but less than the canopy hood option.

APPENDIX A

EMISSION TEST DATA FOR FABRIC FILTERS AT IRON AND STEEL ELECTRIC ARC FOUNDRIES

This appendix presents emission test data for iron and steel electric arc furnaces which was summarized previously in Section 3. Section A.1 shows results of particulate and gaseous sampling and opacity observations conducted by EPA at four iron foundries, and data from two other foundries. Section A.2 presents results of other available data for steel foundry particulate emissions, and Section A.3 shows opacity observations made by EPA at two steel-producing foundries.

A.1 PARTICULATE EMISSION LEVELS AND OPACITY FROM FABRIC FILTERS AT IRON ELECTRIC ARC FURNACES

The following discussion summarizes results of emission sampling conducted on baghouses installed on electric arc furnaces at six different gray iron foundries. Analyses were conducted for both particulate and gaseous pollutants. The concentration of particulate emissions was measured by EPA Method 5 as outlined in the Federal Register, December 31, 1971. Each test consisted of sampling in the baghouse exhaust stack, downstream of the baghouse and exhaust fans.

Plant A has three arc furnaces of 13.6 to 14.5 megagrams (15 to 16 tons) melting capacity each. This is a new foundry and the design of the arc furnace and pollution control equipment were based on experience obtained at Plant B, another foundry operated by the same company. A "heat" encompasses the time from the beginning of charging to the end of the tapping of molten metal. Two automatically-shaken (for cleaning purposes) baghouses provide for gas cleaning. Two furnaces are exhausted to one baghouse while the third furnace is controlled by the other baghouse. The furnaces are equipped with side draft hoods and also hoods above the pouring spout and the slag door. All three hoods are connected to a common take-off box which is under suction from the centrifugal fan at the baghouse. Overhead roof fans and monitors ventilate the furnace scrap bay areas and also withdraw a small amount of air from adjacent areas. An inlet duct (1.5 meters in diameter) about 13 meters (43 feet) above each furnace is manifolded to the main furnace exhaust duct which leads to the baghouse. These inlet ducts are not canopy type hoods but are open end pipes which extend down from the roof area towards each furnace, and are used during charging and tapping of the furnace. Being just an open end duct, and not a complete canopy-type hood, complete control of charging and tapping is not provided, especially during the time of pronounced cross-drafts. The baghouse which was sampled controls two furnaces. The Dacron filter bags withstand a maximum temperature of 135°C (275°F), and the air-to-cloth ratio is 2.54:1. The baghouse inlet and outlet were sampled for particulates (by EPA Method 5), carbon monoxide (using a nondispersive infrared (NDIR) analyzer), hydrocarbons (using a Beckman Hydrocarbon Analyzer), sulfur dioxide (by EPA Reference Method 6), and nitrogen oxides (by EPA Reference Method 7). Both furnaces were performing at design capacity during the tests, and the emission control system appeared to be operating well. Measurements of flow rate averaged 77.0 dry standard cubic meters per minute per megagram of iron produced (2490 dscf/m/ton of iron). Each sample period commenced with the beginning of a heat cycle on one of the furnaces and continued for approximately 3 hours. Generally, the furnaces were on a staggered schedule. An average heat lasted about 70 minutes, and the sampling period encompassed two full heats on each furnace.

Detailed results of the tests are part of this appendix, Tables A-1 and A-2. Average particulate loadings, determined from the four samples, were 8.7, 8.0, 6.4 and 12.0 mg/dscm (0.0038, 0.0035, 0.0028, and 0.0054 grains per dry standard cubic foot, gr/dscf), for an average of 8.9 mg/dscm (0.0039 gr/dscf).

Concurrent with baghouse sampling, visible emission data were obtained for the baghouse stack and for the roof monitor above the furnaces. The highest opacity (6-minute average) observed from the baghouse stack during the nearly 15 hours that readings were taken was 10 percent. The opacity was zero about 80 percent of the time. At the roof monitor, the maximum 6-minute average opacity was 10.0 percent, but the opacity was zero about 90 percent of the entire period of scrutiny. The detailed results of the visible emission readings are presented in this appendix in Tables A-12 through A-19.

Plant B is a new foundry with four electric arc furnaces of 11 to 12 megagrams, 12 to 13 tons melting capacity per heat, each. Particulate emissions from each pair of furnaces are controlled by a common fabric filter dust collector. The furnaces are equipped with side draft hoods and also hoods above the pouring spouts and slag doors. All these hoods are connected to a take-off box which is under suction via the automatically-shaked baghouse by a centrifugal fan. The fan withdraws an average of 97 dscm/m/Mg of iron (3,117 dscf/m/t of iron). The Dacron filter bags withstand a maximum temperature of 135°C (275°F). The air-to-cloth is 2.26. Roof fans and monitors ventilate the furnace and scrap bay areas, also withdrawing small amounts of air along from adjacent foundry areas. The same analyses were carried out at this plant as in Plant A, except only on the outlet of the control device. The two furnaces tested as well as the other two were performing at design capacity and the dust control system was operating normally. The furnaces are on a staggered schedule. The sampling cycle was begun at the beginning of a heat at one furnace, and continued for approximately 3 hours. The average heat lasted about 70 minutes, and sampling covered two full heats on each furnace. Detailed sampling results are presented in this appendix as Table A-3. The average particulate loadings from the three samples were 15.1, 8.7, and 8.7 mg/dscm, averaging 11.0 mg/dscm (0.0066, 0.0038 and 0.0038 gr/dscf for an average of 0.0048 gr/dscf).

Concurrent with baghouse sampling, visible emissions data were obtained for the stack of the baghouse and also the roof monitor vent above the furnaces. The maximum 6-minute average opacity at the baghouse stack was 11.5 percent, although opacity at the stack was zero about 80 percent of the time. At the roof monitor, the maximum 6-minute average opacity was less than 1 percent and the opacity was zero more than 98 percent of the time. Detailed results of visible emission readings are presented in this appendix in Tables A-20 through A-25.

Plant C has two furnaces which produce up to 7 megagram (8 tons) of gray iron each, per heat. Each arc furnace is controlled by a separate fabric filter dust collector, and both furnaces and collectors are retrofits. The furnaces are equipped with roof type hoods and also hoods above the pouring spout and slag door which are connected to individual take-off boxes (57.4 dscm/m/Mg of iron, or 1855 dscf/m/ton). The Orlon filter bags withstand a maximum temperature of 105°C (225°F), and the air-to-cloth ratio is 2.83. Both furnaces were operating during the tests, and the dust control system was operating normally. Furnace production during each test varied, namely, 7, 6 and 4.5 megagrams (8, 7 and 5 tons) per heat, for each of the three sampling periods. Roof fans and monitors ventilate the furnace and scrap bay areas, withdrawing small amounts of air from adjacent areas and exhaust directly to the atmosphere.

Particulate, carbon monoxide, hydrocarbons and sulfur and nitrogen oxides were measured on the stack of one of the dust control devices, downstream of the fan and fabric filter. Each sample was collected over a 1.5 hour period in a manner analogous to previously described sampling. Sampling periods coincided with the beginning of a furnace heat cycle and were finished prior to the end of the heat cycle. An average furnace heat lasted about 90 minutes. The average particulate emissions for the three tests were 36.5, 43.0, 65.4 mg/dscm, averaging 48 mg/dscm (0.01599, 0.01877, and 0.02858 gr/dscf averaging 0.02106 gr/dscf). These results are presented in Table A-4. Emissions at facility C are higher than at the other facilities probably due to two reasons:

1. The collector is manually shaked, and therefore cleaned at irregular intervals and subject to overcleaning. Overcleaning results in a poor filter cake buildup, reduced collection efficiency, and higher emissions.

2. Injection of carbon raiser to the molten bath is carried out via a lance by means of compressed air. Only about 60 to 85 percent of the carbon is dissolved in the metal or retained in the slag, and some carbon escapes the furnace to the baghouse. Due to the very small particle size, only some of the carbon particles are collected in the baghouse.

Visible emissions data were also obtained during sampling periods, for the baghouse exhaust stack and the roof monitor vent above the furnace. The maximum 6-minute average opacity at the stack was 30 percent, but occasional peaks of up to 80 percent were observed for short periods (several seconds only). At the roof monitor, opacity was zero over 98 percent of the time, but the maximum 6-minute average was 32.5 percent. The much higher opacity of emissions from this plant are a consequence of the two somewhat unique characteristics of this particular foundry., the carbon black injection, and manual shaking of the baghouse. Detailed results of the visible emissions readings are presented in this appendix in Tables A-26 through A-31.

Plant D has one furnace which produces 5.4 megagrams (6 tons) of gray iron per heat. The arc furnace is surrounded on three sides by two walls and the transformer room wall, so that fumes from charging and upset conditions (gas puffs escaping through the electrodes holes or other furnace openings) are directed upward to a ventilation fan located above the furnace. Thus, fugitive emissions from the furnace are emitted to the atmosphere in greater concentrations than at the other foundries tested in this program. In the previous foundries, the furnaces were located in large open bay areas, consequently, furnaces were subject to crossdrafts and drift at times sidewards instead of upwards. The furnace is retrofitted with a side draft hood and hoods above the pouring spout and slag door. The gaseous discharge rate to the fabric filter control device averaged 96.4 dscm/m/Mg of iron (3,100 dscf/m/t of iron). The Dacron filter bags withstand a maximum temperature of 135°C (275°F). The air-to-cloth ratio is 2.61. The first test was run only for 1 hour; i.e., only during one heat. However, the next two tests were extended over two heats to capture a greater quantity of dust on the sampling filters. Each test was started at the beginning of two consecutive heats and continued for 1 hour during each heat. An average furnace heat lasted about 70 minutes, and the furnace operated at design capacity. Particulate measurements were made at both the inlet and outlet of the collector. The three measurements showed particulate concentrations of 18.1, 3.1 and 6.3 mg/dscm, averaging 10.5 mg/dscm (0.00792, 0.00137, and 0.002768 gr/dscf for an average of 0.0046 gr/dscf) at the baghouse outlet. The detailed results of the tests are in Tables A-5 and A-6 of this appendix.

Concurrent with sampling of the baghouse, visible emissions data was obtained for the baghouse exhaust stack and the roof monitor vent above the furnace. Opacity at the stack was zero about 98 percent of the time, and the highest 6-minute average opacity was 5.0 percent. On the first sampling period, opacity at the foundry roof vent was zero, 100 percent of the time, but reached a maximum 6-minute average of 7.5 percent on a subsequent test. A summary of visible emission data for charging and tapping and fugitive emissions, and also baghouse emissions, is presented in this appendix in Tables A-32 through A-38.

Plant E operates one electric arc furnace capable of producing either 12.5 megagrams (14 tons) per heat or 6 megagrams/hr (7 tons/hour) of gray iron. Particulate emissions from the furnace are controlled by a fabric filter dust collector. The furnace is equipped with side draft hoods and hoods above the pouring spout and slag door. Roof fans and monitors, discharging directly to the atmosphere, ventilate the furnace bay area. Emissions were sampled at the stack on the baghouse outlet where the flow rate was 86.9 dscm/m/Mg of iron (2810 dscf/m/ton). The bags are made of Dacron and withstand a maximum temperature of 135°C (275°F). The air-to-cloth ratio is 3.1. Average particulate loadings, as determined by the three samples, were 12.8, 23.3, 13.5 mg/dscm, averaging 16.5 mg/dscm (0.0056, 0.0102, and 0.0059 gr/dscf, averaging 0.0072). These data are presented in Table A-7.

During these tests, sampling periods were selected to coincide with different times of the heat cycle - the first test was started when the heat was begun; the second test was started 1 hour after the furnace was started; the third test was started 1.5 hours after the furnace was started. The integration of all three tests should provide a good average because a heat on this furnace lasts about 2.5 to 3 hours.

Visible emission observations were taken only for the stack of the dust collector. Opacity was not evaluated in accordance with standard methods, but rather by frequent spot checks which showed a maximum opacity of 5 percent from the baghouse.

Plant F has two electric arc furnaces of 13.5 to 15.3 megagrams (15 to 17 tons) melting capacity per hour each (27 to 32 megagrams per heat). One baghouse serves the two gray iron producing arc furnaces, two induction holding furnaces and one duplexing arc furnace. The volume withdrawn from each gray iron furnace is 74 dscm/s (157,000 acfm) at 135°C (275°F). Sampling was conducted at the stack outlet of the collector. The furnaces are equipped with side draft hoods, hoods above the pouring and slag doors, and also a direct furnace evacuation tap. All hoods are connected to a takeoff box which is under suction via the baghouse by a centrifugal fan. The direct furnace evacuation system is only in operation for 20 to 25 minutes at the beginning of the melt until the oil from the scrap charge is burned off. (These furnaces melt scrap consisting of 40 percent by weight of borings and turnings which contain up to 10 percent oil). Roof fans and monitors which exhaust directly to the atmosphere ventilate the furnace bay area and adjacent aisles. Sampling was conducted for 2 hours with a test method similar to EPA's Method 5 which meets most of the EPA criteria. In these tests, the sampling period was not selected to coincide with the beginning of a heat cycle on one of the furnaces. Generally, the furnaces are on a staggered schedule.

The highest particulate concentration during these tests was 10.3 mg/dscm (0.0045 gr/dscf). Most of the time, emissions were around 3.2 mg/dscm (0.0014 gr/dscf). The lowest level measured was 1.6 mg/dscm (0.0007 gr/dscf), while the average of 15 measurements was 3.2 mg/dscm (0.0014 gr/dscf). The bags are made of Nomex and withstand a maximum temperature of 204°C (400°F). The data summary of these tests is not available.

Carbon monoxide levels were tested during the EPA tests on four of the foundries, and the data is presented in Tables A-8 through A-11. During all tests, emissions were continuously monitored with a nondispersive infrared analyzer. The sampling location was downstream of the furnace, at the fan, where the temperature is far below the 700°C above which pyrophoric conditions exist. Measurements began during charging and continued until the tap was complete.

At Plant A, carbon monoxide ranged from 33 to 275 ppm with an average (based on three tests) of 95 ppm. The overall hourly emission rates which were measured are rather uniform, the highest differing from the lowest by about 16 percent. The average level, based on three tests, is 0.62 kg/hr per Mg/hr (1.26 lb/hr per ton) of melting capacity.

At Plant B, carbon monoxide ranged from 14 to 142 ppm with an average (based on three tests) of 73 ppm. The overall hourly emissions vary somewhat, the highest differing from the lowest by about 33 percent. The average level of carbon monoxide, based on three tests, is 0.52 kg/hr per Mg/hr of furnace capacity (1.03 lb/hr per ton per hour).

At Plant C, carbon monoxide ranged from 10 to 425 ppm, with an average (based on three tests) of 121 ppm. The overall hourly emissions also vary, the highest differing from the lowest by about 44 percent. The average level of carbon monoxide, based on three tests, is 0.73 kg/hr per Mg/hr (1.45 lb/hr per ton per hour).

At Plant D, carbon monoxide ranged from 0 to 435 ppm with an average (based on three tests) of 104 ppm. The highest measurement differs from the lowest by about 60 percent. The average level of carbon monoxide, based on three tests, is 0.45 kg/hr per Mg/hr (0.775 lb/hr per ton per hour).

During these tests, emissions of sulfur dioxide, hydrocarbons, and nitrogen oxides were also measured. Because no control techniques exist for any of these pollutants (including carbon monoxide) on electric arc furnaces, these measurements are not discussed further. Detailed data on these readings are also reported in Tables A-8 through A-11.

A.2 PARTICULATE EMISSION LEVELS FROM FABRIC FILTERS AT STEEL ELECTRIC ARC FURNACES

Several steel foundries and air pollution control agencies in the U.S. and abroad were contacted to obtain emission test data. These data are presented in Table A-39 (metric units) and repeated in Table A-40 (English units).

Plant A operates a 27.2 Mg (30 short tons) capacity basic electric arc furnace with single slag. Furnace emissions are evacuated by a side draft hood, and the control device is a fabric filter with an air-to-cloth ratio of 2.5:1. The fabric filter is shaken once per heat, at the end of the furnace heat. The baghouse was designed for 95,000 dscm/hr (80,400 acfm); however, it operates at 81,300 dscm/hr (68,800 acfm). The installation was acceptance tested in February 1969, using the ASME Method. Each test lasted 60 minutes, whereas a typical furnace heat with oxygen lancing lasts about 2 hours. Each of the four sampling periods encompassed the time of highest particulate emissions, during oxygen lancing. The following outlet loadings were recorded in the four different tests: 9.17 mg/dscm (0.004 gr/dscf); 5.73 mg/dscm (0.0025 gr/dscf); 6.87 mg/dscm (0.003 gr/dscf); and 36.68 mg/dscm (0.016 gr/dscf). The average outlet loadings were 14.58 mg/dscm (0.0064 gr/dscf).[2]

Plant B operates a 29.92 Mg (33 short tons) capacity basic electric arc furnace with single slag. A side draft hood collects emissions which are exhausted to a fabric filter with an air-to-cloth ratio of 2.5.1. The baghouse was designed for 115,700 dscm/hr (98,000 acfm), but operates at 95,000 dscm/hr (77,000 acfm). The installation was acceptance tested in February 1969, using the ASME Method. Each test lasted 60 minutes, whereas a typical furnace heat with oxygen lancing lasts about 2 hours. Each sampling period included the oxygen lancing operation. The following outlet loadings were recorded in two different tests: 4.6 mg/dscm (0.002 gr/dscf) and 6.87 mg/dscm (0.003 gr/dscf). The average outlet loadings amount to 5.73 mg/dscm (0.002 gr/dscf).[2]

Plant C operates a 33.2 Mg (36.5 short tons) capacity basic electric arc furnace with single slag. Furnace gases are evacuated by direct shell evacuation to a baghouse which handles 43,800 dscm/hr (29,550 acfm). Dacron bags operate at an air-to-cloth ratio of 2. A typical furnace heat with oxygen lancing lasts about 3 to 4 hours, depending on the availability of electrical energy. The tests were carried out using EPA Method 5. The first test encompassed the backcharging and the total test time was 80 minutes. The second test was conducted near the middle of a 5-hour heat, and the total time for the second test was also 80 minutes. The third test, of 30 minutes duration, was conducted after backcharging, but prior to oxygen lancing. The following outlet loadings were recorded in the three different tests: 5.73 mg/dscm (0.00225 gr/dscf); 2.8 mg/dscm (0.001223 gr/dscf); and 8.71 mg/dscm (0.0038 gr/dscf). The average outlet loadings amount to 5.74 mg/dscm (0.0025 gr/dscf).[6]

Plant D operates a 20 to 22 Mg (22 to 24.2 short tons) capacity basic electric arc furnace with single slag. Furnace gases are also evacuated by direct shell evacuation to a fabric filter which treats about 28,000 to 30,000 dscm/hr (16,478 to 17,655 dscfm). Emission sampling tests were conducted at both the inlet and the outlet of the baghouse. Outlet loadings range between 6 and 20 Mg/dscm (0.0026 to 0.0087 gr/dscf). The average outlet loading of 14 tests was 7 mg/dscm (0.003 gr/dscf).[7] The highest loadings were experienced during oxygen lancing. A normal heat for this furnace lasts 2-1/2 hours.

Plant E has two furnaces, one producing 7 Mg (7.7 short tons) per heat and the other 4 Mg per heat (4.4 short tons). The gas volume for the first furnace is 16,000 dscm/hr (9416 dscfm), and for the second is 12,000 dscm/hr (7,062 dscfm). Furnace exhausts are combined and treated in a single fabric filter. The outlet temperature is 70 to 80°C (183 to 200°F). Inlet and outlet loadings were taken during tests; outlet loadings ranged between 1 mg/dscm (0.0026 gr/dscf) and 4 mg/dscm (0.00174 gr/dscf).[7]

The two test results for Plants D and E originate from Germany and were conducted with the VDI particulate test method, which is not identical to EPA Method 5. Based on previous tests carried out in Germany on municipal incinerators, EPA Method 5 collected 30 percent more dust from the cleaned gas stream. The German test results are very similar to the ones obtained from steel electric arc furnaces in this country if this correction is applied.

Plant F operates one basic arc furnace producing 27.27 Mg (30 short tons) per heat, with single slag. Direct shell evacuation directs emissions to a fabric filter. The installation was acceptance tested in May 1973, using EPA Method 5. The gas volume is 174,390 dscm/hr (102,628 dscfm), with temperature of the outlet gas stream of 49°C (88°F). The tests were run during two consecutive heats, the first handling 28.4 Mg (31.2 short tons) and the second 28.2 Mg (31 short tons) of scrap and additives. The following concentrations were measured: inlet, 68.6 mg/dscm (0.0295 gr/dscf); outlet, 6.63 mg/dscm (0.0029 gr/dscf).[8] The entire test lasted 4 hours, since 2 hours are needed to complete each heat.

German sources report that the average outlet loadings from baghouses on arc furnaces in the steel foundry industry average 1.0 mg/cm (0.00043 gr/dscf).[9] The temperature of the gases is not indicated, but assuming 100°C (212°F) at the fabric filter inlet and outlet, emissions will be about 35 percent higher when expressed at standard conditions. Direct shell evacuation is used on these furnaces, and the data applies only to melting and refining emissions.

Another German company reports that for about 30 fabric filters installed in their own plants, and other companies also producing steel castings (mostly with direct shell evacuation), the outlet loadings ranged between 2 mg and 20 mg/dscm (0.00087 and 0.0087 gr/dscf, respectively). Higher emissions were experienced on charges that contained large amounts of swarf.[3]

A French company that has built many control devices for steel electric arc furnaces for general steel production, and which has pioneered some of today's techniques in control of fumes from arc furnaces, was also contacted. The company reports that emissions on steel arc furnaces, similar in size to those used for steel castings, range between 5 and 15 mg/dscm (0.00217 and

0.0065 gr/dscf), and that there are no visible emissions at the stack of the control devices. The higher loadings occur at older installations.[4]

Emissions from well-controlled (fabric filters) electric arc furnaces in steel foundries in Italy, are reported to range between 4 to 12 mg/dscm (0.00174 to 0.00522 gr/dscf).[5] Both the Italian and the French methods for measuring emissions is identical to the German VDI method.

A.3 OPACITY OBSERVATIONS AT STEEL FOUNDRIES

In addition to the above data supplied by plants and suppliers of control devices, it is reported that no visible emissions are detectable at the stack during normal operations, including oxygen lancing periods. Two of the plants were observed by EPA personnel. Plume opacity readings were taken at facilities B and C, according to EPA Method 9, and are reported in Tables A-41 through A-47.

The available opacity data point to two conclusions. The opacity at the stack of arc furnaces processing steel for castings is lower than opacity observed on arc furnaces producing iron. The opacity at the stack for steel producing furnaces seldom exceeds 5 percent, and then only for very short periods. This is due to the fact that raising the carbon level for gray iron calls for introduction of black carbon into the molten bath. Absorption of this carbon is not complete, ranging between 60 to 95 percent. Large amounts of the fine black carbon particles escape collection in the control device and produce an opaque plume. Pitch dark plumes have been observed on gray iron furnaces due to unabsorbed carbon raiser.

With respect to fugitive emissions from the foundry roof, steel foundry electric furnaces have higher opacity than gray iron foundry arc furnaces unless backcharging and tapping emissions are controlled.

The highest 6-minute average opacity recorded due to fugitive emissions at roof fans or monitors on steel-casting furnaces is about 16 percent at one plant and about 10 percent on another. Opacity is highest during tapping, followed by backcharging and then charging. Observed opacities are lower than for arc furnaces in the steel-making industry which control fugitive emissions. The main reason for these differences is the size of the furnaces; steel mill furnaces are much larger than foundry steel furnaces. Consequently, larger quantities of fugitive emissions are generated during furnace operation.

The high opacity levels shown in Tables A-42 and A-43 are due to the fact that at this plant they shake the bags once between heats. Following shaking a certain time is required for a filter cake to build up and allow efficient filtering. During this time, some emissions might escape and cause a visible plume. Inspection of the bags 1 week after the visit of the EPA engineers found that 3 to 4 bags had cracks. Due to the fact that during the rest of the time the opacity was below 5 percent, the higher opacity levels can be explained by excessive emissions from oxygen lancing and dislodging of scrap adhering to the walls.

TABLE A-1

FACILITY A (Baghouse Inlet)

Summary of Results

Run Number	1	2	3	Average
Date	6/19/74	6/19/74	6/20/74	
Test Time - Minutes	210	210	210	210
Total Furnace Capacity - tons	15.5	15.5	15.5	15.5
Flow Rate - ACFM	95431	85721	90990	90714
Flow Rate - DSCFM	72783	65721	76069	69343
Flow rate - DSCFM/ton of furnace capacity	2347	2120	2453	2236
Temperature - ^{o}F	188	185	189	187
Water Vapor - Vol. %	2.5	3.1	1.5	2.4
CO_2 - Vol. % dry	0.3	0.3	0.3	0.3
O_2 - Vol. % dry	19.7	1995	19.5	19.9
CO - Vol % dry		REPORTED ELSEWHERE		
Particulate Emissions				
Probe and filter catch				
gr/DSCF	0.2766	0.3415	0.3201	0.3127
gr/ACF	0.2132	0.2626	0.2491	0.2146
lb/hr	172.5	190.7	192.2	185.1
lb/hr per ton/hour	6.28	7.23	7.0	6.84
Total catch				
gr/DSCF	0.2960	0.3690	0.3250	0.3300
gr/ACF	0.2281	0.2837	0.2529	0.2549
lb/hr	185	206	195	195
lb/hr per ton/hour	5.96	6.64	6.3	6.3

TABLE A-2

FACILITY A (Baghouse Outlet)

Summary of Results

Run Number	1	2	3	4	Average
Date	6/18/74	6/19/74	6/19/74	6/20/74	
Test Time - Minutes	210	210	210	240	217
Total Furnace Capacity - tons	15.5	115.5	15.5	15.5	15.5
Flow rate - ACFM	96674	99797	98140	100111	99349
Flow rate - DSCFM	79992	79331	76140	76985	77465
Flow rate - DSCFM/ton of furnace capacity	2570	2550	2460	2475	2490
Temperature - °F	183	174	185	188	182
Water vapor - Vol. %	212	1.5	2.4	2.9	2.3
CO_2 - Vol. % dry					
O_2 - Vol. % dry			SAME AS INLET		
CO - Vol. % dry					
Particulate Emissions					
Probe and filter catch					
gr/DSCF	0.0038	0.0035	0.0028	0.0054	0.0039
gr/ACF	0.0029	0.0028	0.0022	0.0042	0.0031
lb/hr	2.44	2.38	1.83	3.56	2.59
lb/hr per ton/hour	0.089	0.087	0.067	0.128	0.094
Total catch					
gr/DSCF	0.0072	0.0057	0.0044	0.0073	0.0058
gr/ACF	0.0056	0.0045	0.0034	0.0056	0.0045
lb/hr	4.62	3.89	2.87	4.83	4.05
lb/hr per ton/hour	0.167	0.142	0.105	0.177	0.146

TABLE A-3

FACILITY B (Baghouse Outlet)

Summary of Results

Run Number	1	2	3	Average
Date	6/8/74	6/9/74	6/9/74	
Test Time - Minutes	215	219	214	216
Total Furnace Capacity - - tons	12.5	12.5	12.5	12.5
Flow rate - ACFM	85212	86454	84818	85495
Flow rate - DSCFM	65973	69611	65508	67031
Flow rate - DSCFM/ton of furnace capacity	2615	2790	2662	2680
Temperature - °F	197	171	195	188
Water vapor - Vol. %	3.0	2.8	3.2	3.0
CO_2 - Vol. % dry	0.3	0.2	0.2	0.234
O_2 - Vol. % dry	19.3	20.0	20.0	19.75
CO - Vol. % dry		REPORTED ELSEWHERE		
Particulate Emissions				
Probe and filter catch				
gr/DSCF	0.0066	0.0038	0.0038	0.0048
gr/ACF	0.0051	0.0031	0.0029	0.0037
lb/hr	3.72	2.26	2.11	2.71
lb/hr per ton/hr	0.174	0.1057	0.098	0.126
Total catch				
gr/DSCF	0.0109	0.0004	0.0050	0.0074
GR/ACF	0.0084	0.0052	0.0039	0.0058
lb/hr	6.17	3.81	2.83	4.27
lb/hr per ton/hr	0.288	0.178	0.134	0.20

TABLE A-4

FACILITY C (baghouse Outlet)

Summary of Results

Run Number	1	2	3	Average
Date	9/18/74	9/18/74	9/19/74	
Test Time - Minutes	120	78	120	106
Total Furnace Capacity - tons	7	5	8	6.66
Flow rate - ACFM	14771	15196	14987	14985
Flow rate - DSCFM	12006	12317	12463	12262
Flow rate - DSCFM/ton of furnace capacity	1720	2470	1555	1855
Temperature - °F	184	186	161	177
Water vapor - Vol. %	0.7	0.7	1.0	0.8
CO_2 - Vol. % dry	0.7	0.5	0.5	0.6
O_2 - Vol. % dry	20.6	20.4	21.0	20.7
CO - Vol. % dry		REPORTED ELSEWHERE		
Particulate Emissions				
Probe and filter catch				
gr/DSCF	0.01599	0.01877	0.02858	0.02106
gr/ACF	0.01988	0.02316	0.03437	0.02574
lb/hr	2.03	2.45	3.67	2.71
lb/hr per ton/hr	0.58	0.98	0.9	0.82
Total catch				
gr/DSCF	0.02195	0.02643	0.0409	0.02643
gr/ACF	0.02701	0.03262	0.04926	0.03630
lb/hr	2.96	3.68	5.58	4.07
lb/hr per ton/hr	0.84	0.965	1.6	1.15

TABLE A-5

FACILITY D (Baghouse Inlet)

Summary of Results

Run Number	1	2	3	Average
Date	10/1/74	10/2/74	10/3/74	
Test Time - Minutes	60	120	120	100
Total Furnace Capacity - tons	6	6	6	6
Shop Effluent				
Flow rate - ACFM	21783	23855	22086	22575
Flow rate - DSCFM	19166	15185	19387	17913
Flow rate - DSCFM/ton of furnace capacity	3194	2531	3231	2985
Temperature - °F	124.7	123.5	125.8	124.7
Water vapor - Vol. %	0.8	0.1	0.5	0.47
CO_2 - Vol. % dry	0.8	3.9	3.8	2.8
O_2 - Vol. % dry	19.7	17.7	20.0	19.13
CO - Vol. % dry	0.0	0.0	0.0	0.0
Particulate Emissions				
Probe and filter catch				
gr/DSCF	0.41254	0.28666	0.46288	0.38736
gr/ACF	0.36297	0.26126	0.40631	0.34351
lb/hr	67.76	58.60	76.91	67.76
lb/hr per ton/hr	11.29	11.37	14.93	12.53
Total catch				
gr/DSCF	0.42624	0.29368	0.47761	0.39918
gr/ACF	0.37502	0.26125	0.41924	0.35184
lb/hr	70.01	60.04	79.35	68.80
lb/hr per ton/hr	11.67	11.65	15.49	12.93

TABLE A-6

FACILITY D (Baghouse Outlet)

Summary of Results

Run Number	1	2	3	Average
Date	10/1/74	10/2/74	10/3/74	
Test Time - Minutes	60	120	120	100
Total Furnace Capacity - tons	6	6	6	6
Shop Effluent				
Flow rate - ACFM	16790	21758	18061	18870
Flow rate - DSCFM	15185	20037	20486	18569
Flow rate - DSCFM/ton of furnace capacity	2520	3380	3420	3100
Temperature - °F	112.1	107.0	125.3	114.8
Water vapor - Vol. %	0.8	0.0	0.2	0.3
CO_2 - Vol. % dry	0.8	3.9	3.8	2.8
O_2 - Vol. % dry	19.7	17.7	20.0	19.1
CO - Vol. % dry	0.0	0.0	0.0	0.0
Particulate Emissions				
Probe and filter catch				
gr/DSCF	0.00792	0.00127	0.00268	0.00462
gr/ACF	0.00717	0.00117	0.00237	0.00357
lb/hr	1.03	0.22	0.42	0.593
lb/hr per ton/hr	0.2	0.042	0.082	0.108
Total catch				
gr/DSCF	0.02353	0.00319	0.00502	0.01058
gr/ACF	0.02128	0.00294	0.00443	0.00955
lb/hr	3.06	0.55	0.78	1.463
lb/hr per ton/hr	0.51	0.063	0.076	0.213

TABLE A-7

FACILITY E (Baghouse Outlet)

Summary of Results

Run Number	1	2	3	Average
Date	5/6/74	5/7/74	5/7/74	
Test Time - Minutes	60	60	60	60
Total Furnace Capacity - tons	15	15	15	15
Flow rate - ACFM	53500	47500	48100	49700
Flow rate - DSCFM	54118	39857	40642	42205
Flow rate - DSCFM/ton of furnace capacity	3600	2600	2710	2990
Temperature - °F	106	126	128	120
Water vapor - Vol. %	0.083	0.47	0.47	0.341
CO_2 - Vol. % dry		NOT RECORDED		
O_2 - Vol. % dry	20.7	20.5	20.45	20.55
CO - Vol. % dry	0.0	0.1	0.1	0.1
Particulate Emissions				
Probe and filter catch				
gr/DSCF	0.0056	0.010184	0.005935	0.00723
gr/ACF	0.00483	0.001596	0.000890	0.00243
lb/hr	2.04	3.27	1.93	2.41
lb/hr per ton/hr	0.292	0.46	0.286	0.3462

TABLE A-8

Gaseous Emission Data

Facility A

Summary of Results

Run Number	1	2	3	Average
Date	6/19/74	6/19/74	6/20/74	-
Carbon Monoxide Emissions				
Average ppm (by volume)	95	88	104	95
lb/hr	34.93	31.38	37.13	34.61
lb/hr per ton per hour	1.27	1.14	1.36	1.26
Nitrogen Oxides (as NO_2) Emissions				
Average ppm (by volume)	3.37	1.59	2.48	2.48
lb/hr	1.87	0.851	1.36	1.36
lb/hr per ton per hour	0.068	0.031	0.0495	0.0395
Hydrocarbon (as CH_4) Emissions				
Average ppm (by volume)	7.4	7.8	7.6	7.6
lb/hr	1.554	1.588	1.566	1.566
lb/hr per ton per hour	0.056	0.058	0.057	0.057
Sulfur Dioxide Emissions				
Average ppm (by volume)	4.86	5.26	4.40	4.84
lb/hr	3.78	3.93	3.32	3.68
lb/hr per ton per hour	0.137	0.144	0.121	0.134

TABLE A-9

Facility B

Summary of Result

Run Number	1	2	3	Average
Date	6/8/74	6/9/74	6/9/74	-
Carbon Monoxide Emissions				
Average ppm (by volume)	75	84	59	73
lb/hr	22.4	26.5	17.6	22.2
lb/hr per ton per hour	1.04	1.24	0.82	1.03
Nitrogen Oxides (as NO_2) Emissions				
Average ppm by volume	3.24	52.14	—	27.1
lb/hr	1.34	25.0	—	13.2
lb/hr per ton per hour	0.062	1.162	—	0.612
Hydrocarbon (as CH_4) Emissions				
Average ppm (by volume)	8.6	9.6	11.5	9.9
lb/hr	1.47	1.73	1.96	1.72
lb/hr per ton per hour	0.068	0.08	0.09	0.079
Sulfur Dioxide Emissions				
Average ppm (by volume)	2.88	0.66	1.37	1.64
lb/hr	1.86	0.45	0.88	1.06
lb/hr per ton per hour	0.086	0.02	0.040	0.049

TABLE A-10

Facility C

Summary of Results

Run Number	1	2	3	Average
Date	9/18/74	9/18/74	9/19/74	-
Carbon Monoxide Emissions				
Average ppm (by volume)	137	88.25	138.5	121.25
lb/hr	5.15	3.4	6.07	4.873
lb/hr per ton per hour	1.47	1.36	1.52	1.45
Nitrogen Oxides (as NO_2) Emissions				
Average ppm (by volume	8.95	9.57	9.97	8.50
lb/hr	0.754	0.818	0.861	0.811
lb/hr per ton per hour	0.214	0.218	0.23	0.22
Hydrocarbons (Total) Emissions				
Average ppm (by volume)	5.6	—	—	5.0
lb/hr	0.180	—	—	0.180
lb/hr per ton per hour	0.0515	—	—	0.0515
Sulfur Dioxide Emissions				
Average ppm (by volume)	14.1	17.6	17.3	16.3
lb/hr	1.655	2.091	2.082	1.943
lb/hr per ton per hour	0.47	0.55	0.54	0.52

TABLE A-11

Facility D

Summary of Results

Run Number	1	2	3	Average
Date	10/1/74	10/2/74	10/3/74	-
Carbon Monoxide Emissions				
Average ppm (by volume)	107	143	60	103
lb/hr	4.805	5.166	2.03	4.00
lb/hr per ton per hour	0.933	1.00	0.394	0.775
Nitrogen Oxides (as NO_2) Emissions				
Average ppm (by volume)				
lb/hr		SAMPLES IMPROPERLY COLLECTED		
lb/hr per ton of furnace capacity				
Hydrocarbon (as CH_4) Emissions				
Average ppm (by volume)	2.88	7.3	10.85	7.01
lb/hr	0.604	1.487	2.23	1.44
lb/hr per ton per hour	0.117	0.289	0.433	0.279
Sulfur Dioxide Emissions				
Average ppm (by volume)	1.7	2.5	17.7	7.3
lb/hr	0.245	0.492	3.16	1.29
lb/hr per ton per hour	0.047	0.095	0.613	0.248

TABLE A-12

FACILITY A

Summary of Visible Emissions

Date: **June 18, 1974**

Type of Plant: **Gray Iron Foundry**

Type of Discharge: **Particulates**

Location of Discharge: **Stack**

Height of Point of Discharge: **40 Feet**

Description of Background: **Black Building**

Description of Sky: **Clear**

Wind Direction: **North**

Color of Plume: **Brown**

Duration of Observation: **4 Hours, 15 Minutes**

Distance from Observer to Discharge Point: **100 Feet**

Height of Observation Point: **Ground Level**

Direction of Observer from Discharge Point: **North**

Wind Velocity: **10 to 15 mph**

Detached Plume: **No**

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
1	10:45	10:50	0	0
2	10:50	10:56	0	0
3	10:56	11:02	0	0
4	10:02	11:08	0	0
5	11:08	11:14	0	0
6	11:14	11:20	80	3.35
7	11:26	11:32	120	5
8	11:32	11:38	120	5
9	11:44	11:50	20	0.836
10	11:50	11:56	10	0.418
11	12:02	12:08	0	0
12	12:08	12:19	0	0
13	12:14	12:20	0	0
14	12:20	12:26	100	4.18
15	12:26	12:32	65	2.7
16	12:32	12:38	15	0.627
17	12:38	12:44	100	4.18
18	12:44	12:50	85	3.5
19	12:50	12:56	80	3.35
20	12:56	1:02	5	0.21

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
21	1:02	1:08	0	0
22	1:08	1:14	0	0
23	1:14	1:20	30	1.25
24	1:20	1:26	210	8.77
25	1:26	1:32	165	6.45
26	1:32	1:38	240	10.00
27	1:38	1:44	170	7.1
28	1:44	1:50	5	0.21
29	1:50	1:56	40	1.66
30	1:56	2:02	5	0.21
31	2:02	2:08	5	0.21
32	2:08	2:14	5	0.21
33	2:14	2:20	55	2.39
34	2:20	2:26	85	3.5
35	2:26	2:32	0	0
36	2:32	2:38	0	0
37	2:38	2:44	90	3.75
38	2:44	2:50	95	3.95
39	2:50	2:56	105	4.36
40	2:56	3:02	0	0

Sketch Showing How Opacity Varied With Time:

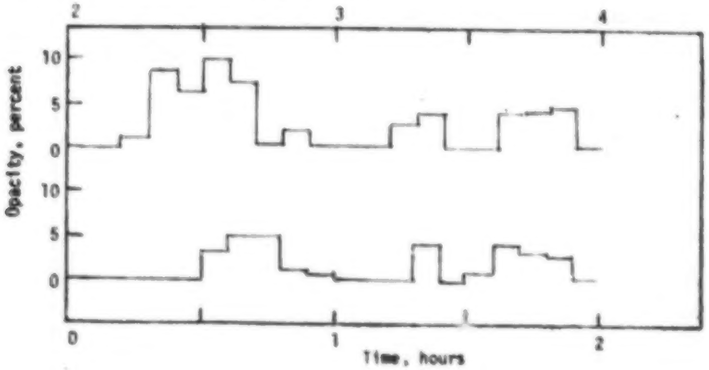


TABLE A-13

FACILITY A

Summary of Visible Emissions

Date: June 18, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 24 Feet

Location of Discharge: Roof Vents

Height of Observation Point: 60 Feet

Height of Point of Discharge: 3 Feet

Direction of Observer from Discharge Point: East of Roof Fan

Description of Background: Sky

Description of Sky: Sunny Blue Sky

Wind Direction: North

Wind Velocity: 10 to 15 mph

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 4 Hours

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
1	10:50	10:56	75	3.13
2	11:56	11:02	35	1.46
3	11:02	11:08	5	0.21
4	11:08	11:14	0	0
5	11:14	11:20	0	0
6	11:20	11:26	0	0
7	11:26	11:32	0	0
8	11:32	11:38	0	0
9	11:38	11:44	0	0
10	11:44	11:50	0	0
11	11:50	11:56	90	3.75
12	11:56	12:02	55	2.39
13	12:02	12:08	110	4.58
14	12:08	12:14	55	2.39
15	12:14	12:20	0	0
16	12:20	12:26	150	6.24
17	12:26	12:32	10	0.418
18	12:32	12:38	30	1.25
19	12:38	12:44	0	0
20	12:44	12:50	95	3.95

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
21	12:50	12:56	0	0
22	12:56	1:02	45	1.875
23	1:02	1:08	5	0.21
24	1:08	1:14	0	0
25	1:14	1:20	260	10.08
26	1:20	1:26	30	1.25
27	1:26	1:32	45	1.87
28	1:32	1:38	0	0
29	1:38	1:44	195	8.1
30	1:44	1:50	25	1.14
31	1:50	1:56	0	0
32	1:56	2:02	0	0
33	2:02	2:08	0	0
34	2:08	2:14	85	3.5
35	2:14	2:20	135	5.63
36	2:20	2:26	110	4.58
37	2:26	2:32	0	0
38	2:32	2:38	0	0
39	2:38	2:44	245	10.02
40	2:44	2:50	75	3.13

Sketch Showing How Opacity Varied With Time:

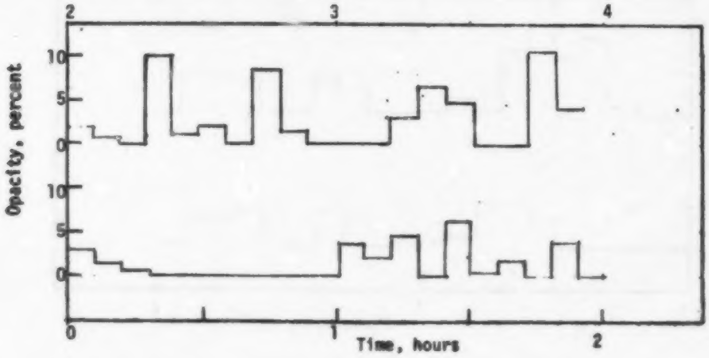


TABLE A-14

FACILITY A

Summary of Visible Emissions

Date: June 19, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 100 Feet

Location of Discharge: Stack

Height of Observation Point: Ground Level

Height of Point of Discharge: 40 Feet

Direction of Observer from Discharge Point: North

Description of Background: Dark Gray Side of Building

Description of Sky: Clear

Wind Direction: Calm

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 25 Minutes

SUMMARY OF AVERAGE OPACITY — SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	10:00	10:06	0	0	21	12:00	12:06	115	4.78
2	10:06	10:12	5	0.21	22	12:06	12:12	125	5.22
3	10:12	10:18	0	0	23	12:12	12:18	135	5.63
4	10:18	10:24	10	0.417	24	12:18	12:24	65	2.7
5	10:24	10:30	80	3.33	25	12:24	12:30	95	3.6
6	10:30	10:36	90	3.75	26	12:30	12:36	35	1.46
7	10:36	10:42	45	1.875	27	12:36	12:42	10	0.417
8	10:42	10:48	50	2.1	28	12:42	12:48	0	0
9	10:48	10:54	0	0	29	12:48	12:54	5	0.21
10	10:54	11:00	80	3.33	30	12:54	1:00	5	0.21
11	11:00	11:06	95	3.97	31	1:00	1:06	5	0.21
12	11:06	11:12	65	2.7	32	1:06	1:12	5	0.21
13	11:12	11:18	15	0.625	33	1:12	1:18	5	0.21
14	11:18	11:24	40	1.67	34	1:18	1:24	5	0.21
15	11:24	11:30	45	1.87	35				
16	11:30	11:36	0	0	36				
17	11:36	11:42	10	0.417	37				
18	11:42	11:48	45	1.87	38				
19	11:48	11:54	120	5	39				
20	11:54	12:00	55	2.29	40				

Sketch Showing How Opacity Varied With Time:

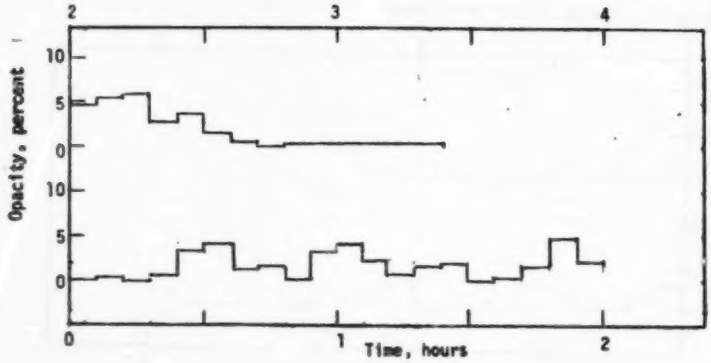


TABLE A-15

FACILITY A

Summary of Visible Emissions

Date: June 19, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Roof Vent

Distance from Observer to Discharge Point: 24 Feet

Location of Discharge: Over Furnace No. 2

Height of Observation Point: 60 Feet

Height of Point of Discharge: 3 Feet

Direction of Observer from Discharge Point: Sun in the Back of Observer

Description of Background: Sky

Description of Sky: Cloudy, Bright Sun

Wind Direction: Not Recorded

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 18 Minutes

SUMMARY OF AVERAGE OPACITY | SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	10:00	10:06	70	2.9	21	12:00	12:06	0	0
2	10:06	10:12	15	0.625	22	12:06	12:12	0	0
3	10:12	10:18	0	0	23	12:12	12:18	0	0
4	10:18	10:24	0	0	24	12:18	12:24	20	0.417
5	10:24	10:30	40	1.66	25	12:24	12:30	50	2.1
6	10:30	10:36	60	2.5	26	12:30	12:36	0	0
7	10:36	10:42	0	0	27	12:36	12:42	0	0
8	10:42	10:48	0	0	28	12:42	12:48	0	0
9	10:48	10:54	0	0	29	12:48	12:54	0	0
10	10:54	11:00	0	0	30	12:54	1:00	0	0
11	11:00	11:06	60	2.5	31	1:00	1:06	0	0
12	11:06	11:12	10	0.417	32	1:06	1:12	0	0
13	11:12	11:18	20	0.83	33	1:12	1:18	55	2.29
14	11:18	11:24	0	0	34				
15	11:24	11:30	0	0	35				
16	11:30	11:36	60	2.5	36				
17	11:36	11:42	0	0	37				
18	11:42	11:48	0	0	38				
19	11:48	11:54	0	0	39				
20	11:54	12:00	35	1.46	40				

Sketch Showing How Opacity Varied With Time:

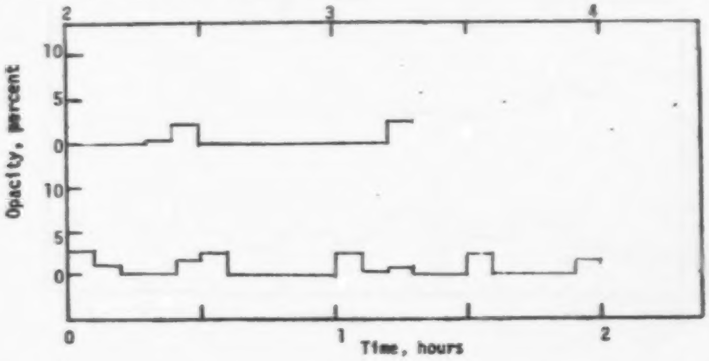


TABLE A-16

FACILITY A

Summary of Visible Emissions

Date: June 19, 1975

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 100 Feet

Location of Discharge: Stack

Height of Observation Point: Ground Level

Height of Point of Discharge: 40 Feet

Direction of Observer from Discharge Point: North

Description of Background: Dark Gray Side of Building

Description of Sky: Cloudy and Sunny (after 6:30 p.m.)

Wind Direction: Not Recorded

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 58 Minutes

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
1	4:04	4:10	0	0
2	4:10	4:16	5	0.21
3	4:16	4:22	15	0.627
4	4:22	4:28	20	0.83
5	4:28	4:34	0	0
6	4:34	4:40	50	2.1
7	4:40	4:46	90	3.73
8	4:46	4:52	130	5.42
9	4:52	4:58	120	5
10	4:58	5:04	120	5
11	5:04	5:10	60	2.5
12	5:10	5:16	15	0.62
13	5:16	5:22	5	0.21
14	5:22	5:28	5	0.21
15	5:28	5:34	5	0.21
16	5:34	5:40	10	0.21
17	5:40	5:46	95	4
18	5:46	5:52	110	4.6
19	5:52	5:58	140	5.8
20	5:58	6:04	125	5

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
21	6:04	6:10	35	1.46
22	6:10	6:16	15	0.625
23	6:16	6:22	45	1.875
24	6:22	6:28	90	3.73
25	6:28	6:34	60	2.5
26	6:34	6:40	65	2.71
27	6:40	6:46	0	0
28	6:46	6:52	35	1.76
29	6:52	6:58	0	0
30	6:58	7:04	90	3.73
31	7:04	7:10	120	5
32	7:10	7:16	125	5.22
33	7:16	7:22	100	9.17
34	7:22	7:28	5	0.21
35	7:28	7:34	0	0
36	7:34	7:40	25	1.04
37	7:40	7:46	75	3.13
38	7:46	7:52	55	2.3
39	7:52	7:58	5	0.21
40	7:58	8:04		

Sketch Showing How Opacity Varied With Time:

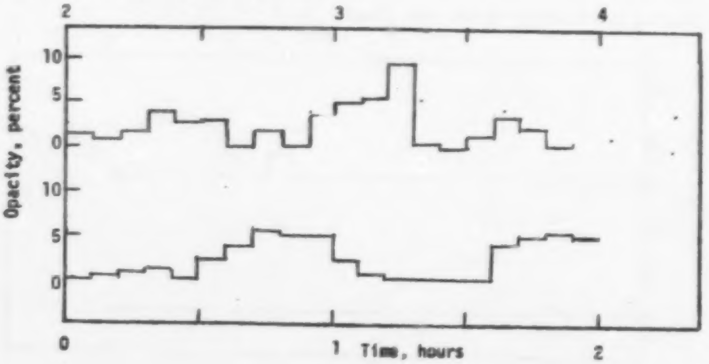


TABLE A-17

FACILITY A

Summary of Visible Emissions

Date: June 19, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Roof Vent

Distance from Observer to Discharge Point: 24 Feet

Location of Discharge: Over Furnace No. 2

Height of Observation Point: 60 Feet

Height of Point of Discharge: 3 Feet

Direction of Observer from Discharge Point: East of Roof Fan

Description of Background: Sky

Description of Sky: Cloudy, Rainy to Partly Cloudy

Wind Direction: Not Recorded

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 4 Hours

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	4:04	4:10	0	0	21	6:04	6:10	0	
2	4:10	4:16	0	0	22	6:10	6:16	0	
3	4:16	4:22	0	0	23	6:16	6:22	0	
4	4:22	4:28	20	0.8	24	6:22	6:28	0	
5	4:28	4:34	5	0	25	6:28	6:34	0	
6	4:34	4:40	0	0	26	6:39	6:40	0	
7	4:40	4:46	0	0	27	6:40	6:46	0	
8	4:46	4:52	0	0	28	6:46	6:52	0	
9	4:52	4:58	0	0	29	6:52	6:58	0	
10	4:58	5:04	0	0	30	6:58	7:04	0	
11	5:09	5:10	0	0	31	7:04	7:10	0	
12	5:10	5:16	0	0	32	7:10	7:16	0	
13	5:16	5:22	0	0	33	7:16	7:22	0	
14	5:22	5:28	0	0	34	7:22	7:28	65	2.6
15	5:28	5:34	0	0	35	7:28	7:34	0	
16	5:34	5:40	0	0	36	7:34	7:40	0	
17	5:40	5:46	0	0	37	7:40	7:46	0	
18	5:46	5:50	0	0	38	7:46	7:52	0	
19	5:52	5:58	0	0	39	7:52	7:58	0	
20	5:58	6:04	0	0	40	7:58	8:04	0	

Sketch Showing How Opacity Varied With Time:

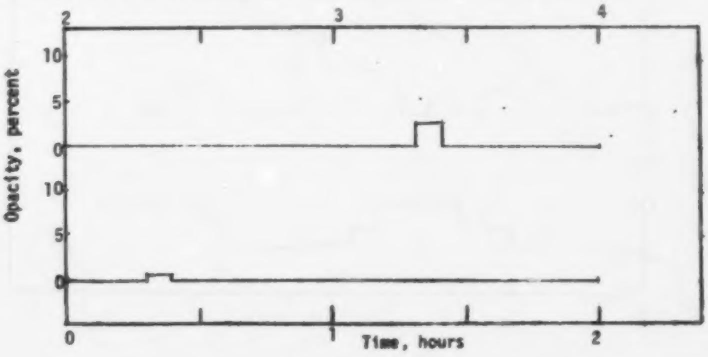


TABLE A-18

FACILITY A

Summary of Visible Emissions

Date: June 20, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 100 ft., 40 ft. above observer

Location of Discharge: Stack

Height of Observation Point: Ground level

Height of Point of Discharge: 80 ft.

Direction of Observer from Discharge Point: North

Description of Background: Dark Gray Side of Building

Description of Sky: Clear

Wind Direction: Not Recorded

Wind Velocity: 15 mph

Color of Plume: Brown

Detached Plume: No

Duration of Observation:

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
1	9:20	9:26	0	0
2	9:26	9:32	0	0
3	9:32	9:38	0	0
4	9:38	9:44	0	0
5	9:44	9:50	0	0
6	9:50	9:56	15	2.92
7	9:56	10:02	0	0
8	10:02	10:08	0	0
9	10:08	10:14	0	4.37
10	10:14	10:20	0	0
11	10:20	10:26	0	0
12	10:26	10:32	0	0
13	10:32	10:38	0	1.25
14	10:38	10:44	0	0
15	10:44	10:50	0	0
16	10:50	10:56	0	1.45
17	10:56	11:02	0	0.417
18	10:02	11:08	0	1.25
19	11:08	11:14	10	0
20	11:14	11:20	40	0.84

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
21	11:20	11:26	120	5
22	11:26	11:32	125	5.13
23	11:32	11:38	50	2.08
24	11:38	11:44	60	5
25	11:44	11:50	150	6.25
26	11:50	11:56	55	2.30
27	11:56	12:02	15	6.27
28	12:02	12:08	5	0.21
29	12:08	12:14	0	0
30	12:14	12:20	0	0
31	12:20	12:26	0	0
32	12:26	12:32	0	0
33	12:32	12:38	0	0
34				
35				
36				
37				
38				
39				
40				

Sketch Showing How Opacity Varied With Time:

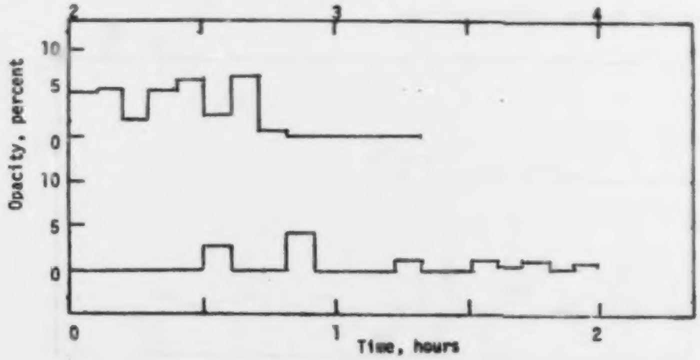


TABLE A-19

FACILITY A

Summary of Visible Emissions

Date: June 20, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Roof Vent

Distance from Observer to Discharge Point: 24 Feet

Location of Discharge: Over Furnace No. 2

Height of Observation Point: 60 Feet

Height of Point of Discharge: 3 Feet

Direction of Observer from Discharge Point: East of the Vent

Description of Background: Sky

Description of Sky: Sunny with Haze

Wind Direction: Not Recorded

Wind Velocity: 15 mph

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 18 Minutes

SUMMARY OF AVERAGE OPACITY | SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	9:20	9:26	0	0	21	11:20	11:26	80	3.34
2	9:26	9:32	0	0	22	11:26	11:32	0	0
3	9:32	9:38	0	0	23	11:32	11:38	0	0
4	9:38	9:44	0	0	24	11:38	11:44	0	0
5	9:44	9:50	0	0.21	25	11:44	11:50	5	0.21
6	9:50	9:56	70	2.92	26	11:50	11:56	50	2.08
7	9:56	10:02	0	0	27	11:56	12:02	0	0
8	10:02	10:08	0	0	28	12:02	12:08	20	0.84
9	10:08	10:14	105	4.37	29	12:08	12:14	0	0
10	10:14	10:20	0	0	30	12:14	12:20	0	0
11	10:20	10:26	0	0	31	12:20	12:26	55	2.3
12	10:26	10:32	0	0	32	12:26	12:32	5	0.21
13	10:32	10:38	30	1.25	33	12:32	12:38	100	4.17
14	10:38	10:44	0	0	34				
15	10:44	10:50	0	0	35				
16	10:50	10:56	35	1.45	36				
17	10:56	11:02	10	0.417	37				
18	11:02	11:08	30	1.25	38				
19	11:08	11:14	0	0	39				
20	11:14	11:20	20	0.84	40				

Sketch Showing How Opacity Varied With Time:

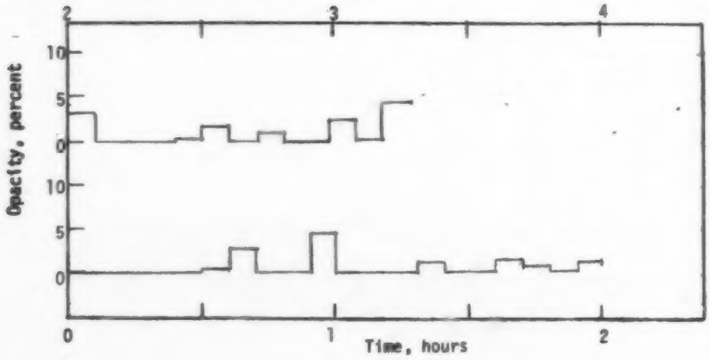


TABLE A-20

FACILITY B

Summary of Visible Emissions

Date: July 8, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 125 Feet

Location of Discharge: Stack

Height of Observation Point: Ground Level

Height of Point of Discharge: 50 Feet

Direction of Observer from Discharge Point: South-East

Description of Background: Gray Buildings and Equipment

Description of Sky: Sunny, Scattered Clouds, Blue Sky, Humid, 95°F

Wind Direction: Calm

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 40 Minutes

SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	1:20	1:26	0	0	21	3:26	3:32	25	1.0
2	1:27	1:32	0	0	22	3:32	3:36	35	1.46
3	1:33	1:39	0	0	23	3:37	3:42	0	0
4	1:45	1:51	0	0	24	3:42	3:46	30	1.25
5	1:52	1:56	55	2.2	25	3.46	3:52	10	0.417
5	1:57	2:02	10	0.41	26	3:52	3:58	0	0
7	2:03	2:08	0	0	27	3:58	4:04	0	0
8	2:08	2:14	85	3.54	28	4:04	4:10	0	0
9	2:14	2:20	30	1.25	29	4:10	4:16	115	3.83
10	2:20	2:26	65	2.7	30	4:16	4:22	130	5.42
11	2:26	2:32	25	1.04	31	4:22	4:28	50	2.08
12	2:32	2:38	0	0	32	4:28	4:34	55	2.29
13	2:38	2:44	0	0	33	4:34	4:40	65	2.7
14	2:44	2:50	0	0	34	4:40	4:46	195	6.05
15	2:50	2:56	0	0	35	4:46	4:52	45	1.875
16	2:56	3:02	0	0	36	4:52	4:58	0	0
17	3:02	3:08	0	0	37	4:58	5:04	0	0
18	3:08	3:14	0	0	38				
19	3:14	3:20	45	1.88	39				
20	3:21	3:26	50	0.21	40				

Sketch Showing How Opacity Varied With Time:

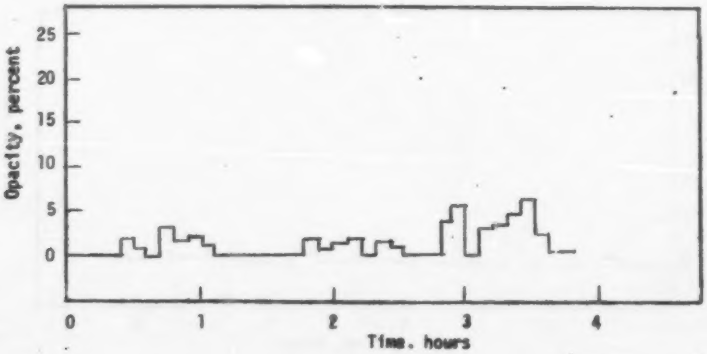


TABLE A-21

FACILITY B

Summary of Visible Emissions

Date: July 8, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 30 Feet

Location of Discharge: Roof Vent

Height of Observation Point: At Vent Level

Height of Point of Discharge: 3 Feet Above Roof

Direction of Observer from Discharge Point: 30 Feet South of Discharge Point

Description of Background: Sky

Description of Sky: Scattered Clouds

Wind Direction: Calm

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 40 Minutes

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
1	1:20	1:26	0	0
2	1:26	1:32	0	0
3	1:32	1:38	0	0
4	1:38	1:44	0	0
5	1:44	1:50	20	0.835
6	1:50	1:56	0	0
7	1:56	2:02	0	0
8	2:02	2:08	0	0
9	2:08	2:14	0	0
10	2:14	2:20	0	0
11	2:20	2:26	0	0
12	2:26	2:32	0	0
13	2:32	2:38	0	0
14	2:38	2:44	0	0
15	2:44	2:50	0	0
16	2:50	2:56	0	0
17	2:56	3:02	0	0
18	3:02	3:08	0	0
19	3:08	3:14	0	0
20	3:14	3:20	0	0
21	3:20	3:26	0	0
22	3:26	3:32	0	0
23	3:32	3:38	0	0
24	3:38	3:44	20	0.83
25	3:44	3:50	20	0.83
26	3:50	3:56	0	0
27	3:56	4:02	0	0
28	4:02	4:08	0	0
29	4:08	4:14	5	0.2
30	4:14	4:20	5	0.2
31	4:20	4:26	5	0.2
32	4:26	4:32	5	0.2
33	4:32	4:38	5	0.2
34	4:38	4:44	0	0
35	4:44	4:50	15	0.62
36	4:50	4:56	0	0
37	4:56	5:02	0	0
38	5:02	5:08	0	0
39				
40				

Sketch Showing How Opacity Varied With Time:

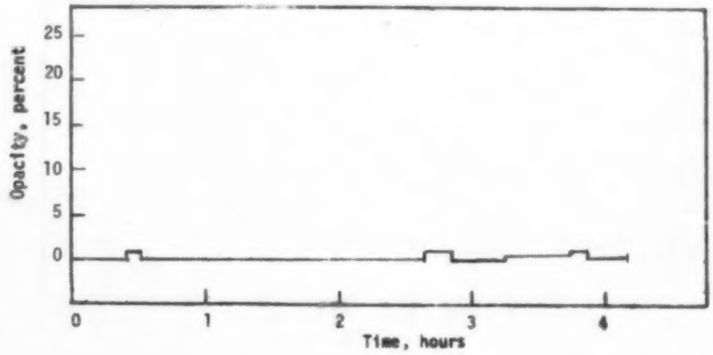


TABLE A-22

FACILITY B

Summary of Visible Emissions

Date: July 9, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 125 Feet

Location of Discharge: Stack

Height of Observation Point: Ground Level

Height of Point of Discharge: 50 Feet

Direction of Observer from Discharge Point: South-East

Description of Background: Gray Buildings and Equipment

Description of Sky: Clear

Wind Direction: Calm

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 36 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	7:55	8:01	25	1	21	9:56	10:02	10	0.417
2	8:01	8:07	15	0.625	22	10:02	10:08	0	0
3	8:07	8:13	30	1.25	23	10:08	10:14	0	0
4	8:13	8:19	30	1.25	24	10:14	10:20	0	0
5	8:19	8:25	55	2.29	25	10:20	10:26	0	0
6	8:26	8:32	0	0	26	10:26	10:32	25	1.0
7	8:32	8:38	10	0.41	27	10:32	10:38	10	0.417
8	8:38	8:44	15	0.625	28	10:38	10:44	10	0.417
9	8:44	8:50	135	5.63	29	10:44	10:50	0	0
10	8:50	8:56	130	5.42	30	10:50	10:56	0	0
11	8:56	9:02	110	4.5	31	10:56	11:02	0	0
12	9:02	9:08	70		32	11:02	11:08	0	0
13	9:08	9:14	0	0	33	11:08	11:14	0	0
14	9:14	9:20	0	0	34	11:14	11:20	0	0
15	9:20	9:26	45	1.875	35	11:20	11:26	10	0.417
16	9:26	9:32	0	0	36	11:26	11:32	5	0.20
17	9:32	9:38	0	0	37	11:32	11:36	0	0
18	9:38	9:44	5	6.20	38				
19	9:44	9:50	5	0.20	39				
20	9:50	9:56	25	1.0	40				

Sketch Showing How Opacity Varied With Time:

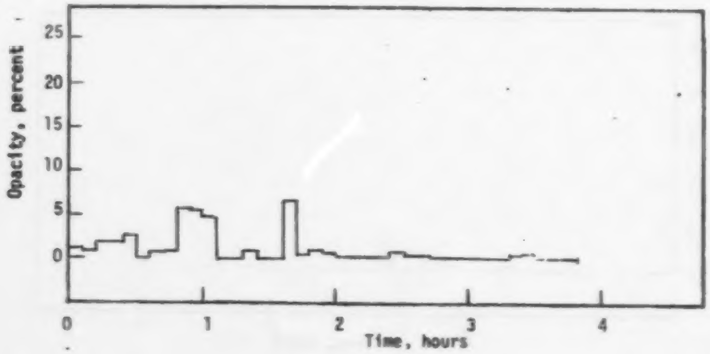


TABLE A-23

FACILITY B

Summary of Visible Emissions

Date: July 9, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point:

Location of Discharge: Roof Vent

Height of Observation Point:

Height of Point of Discharge: 3 Feet Above Roof

Direction of Observer from Discharge Point: 30 Feet South of Discharge Point

Description of Background: Sky

Description of Sky: Scattered Clouds

Wind Direction: Calm

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 36 Minutes

SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	8:00	8:06	0	0	21	10:00	10:10	0	0
2	8:06	8:12	0	0	22	10:10	10:16	0	0
3	8:12	8:18	0	0	23	10:16	10:22	0	0
4	8:18	8:24	0	0	24	10:22	10:28	0	0
5	8:24	8:30	0	0	25	10:28	10:34	0	0
6	8:30	8:36	0	0	26	10:34	10:42	0	0
7	8:36	8:42	0	0	27	10:42	10:48	0	0
8	8:42	8:48	0	0	28	10:48	10:54	0	0
9	8:48	8:54	0	0	29	10:54	11:00	0	0
10	8:54	9:00	0	0	30	11:00	11:06	0	0
11	9:00	9:06	0	0	31	11:06	11:12	0	0
12	9:06	9:12	0	0	32	11:12	11:18	0	0
13	9:12	9:18	15	0.625	33	11:18	11:24	0	0
14	9:18	9:24	0	0	34	11:24	11:30	0	0
15	9:24	9:30	0	0	35	11:30	11:36	0	0
16	9:30	9:36	0	0	36	11:36	11:40	0	0
17	9:36	9:42	15	0.625	37				
18	9:42	9:48	0	0	38				
19	9:48	9:54	0	0	39				
20	9:54	10:00	0	0	40				

Sketch Showing How Opacity Varied With Time:

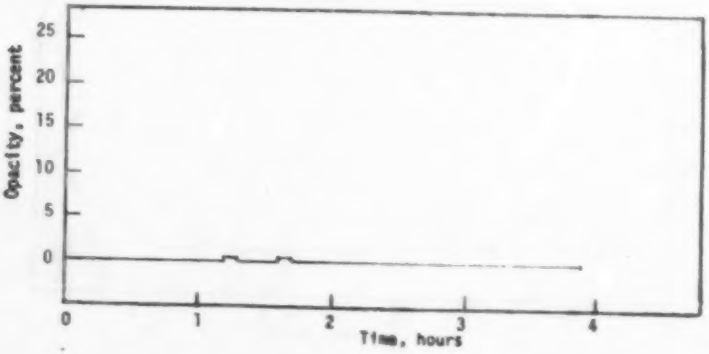


TABLE A-24

FACILITY B

Summary of Visible Emissions

Date: July 9, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 125 Feet

Location of Discharge: Stack

Height of Observation Point: Ground Level

Height of Point of Discharge: 50 Feet

Direction of Observer from Discharge Point: South-East

Description of Background: Gray Buildings and Equipment

Description of Sky: Clear

Wind Direction: Calm

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 40 Minutes

SUMMARY OF AVERAGE OPACITY | SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	1:20	1:26	5	0.20	21	3:20	3:26	75	3.12
2	1:26	1:32	0	0	22	3:26	3:32	25	1.0
3	1:32	1:38	0	0	23	3:32	3:38	0	0
4	1:38	1:44	0	0	24	3:38	3:44	0	0
5	1:44	1:50	60	2.5	25	3:44	3:50	105	4.28
6	1:50	1:56	0	0	26	3:50	3:56	150	6.25
7	1:56	2:02	0	0	27	3:56	4:02	85	3.51
8	2:02	2:08	0	0	28	4:02	4:08	0	0
9	2:08	2:14	0	0	29	4:08	4:14	0	0
10	2:14	2:20	0	0	30	4:14	4:20	125	5.22
11	2:20	2:26	0	0	31	4:20	4:26	180	7.5
12	2:26	2:32	27	1.125	32	4:26	4:32	150	6.27
13	2:32	2:38	0	0	33	4:32	4:38	90	3.73
14	2:38	2:44	85	3.53	34	4:38	4:44	120	5
15	2:44	2:50	95	4.00	35	4:44	4:50	275	11.45
16	2:50	2:56	5	0.2	36	4:50	4:56	225	9.38
17	2:56	3:02	0	0	37				
18	3:02	3:08	0	0	38				
19	3:08	3:14	0	0	39				
20	3:14	3:20	10	0.417	40				

Sketch Showing How Opacity Varied With Time:

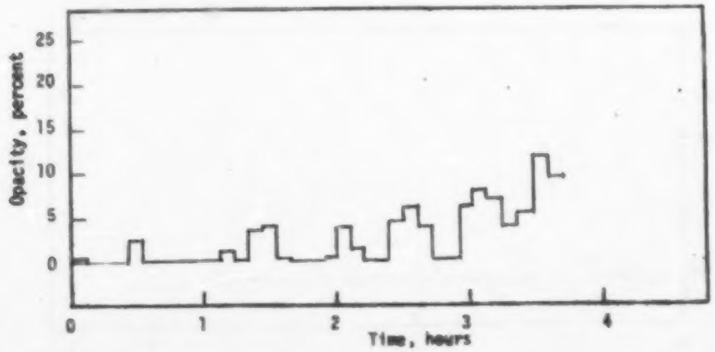


TABLE A-25

FACILITY B

Summary of Visible Emissions

Date: July 9, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Location of Discharge: Roof Vent

Height of Point of Discharge: 3 Feet Above Roof

Description of Background: Sky

Description of Sky: Clear

Distance from Observer to Discharge Point: 30 Feet

Height of Observation Point: At Vent Level

Direction of Observer from Discharge Point: 30 Feet South of Discharge Point

Wind Direction: Calm

Wind Velocity: Not Recorded

Color of Plume: Brown

Detached Plume: No

Duration of Observation: 3 Hours, 30 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	1:30	1:36	0	0	21	3:30	3:36	0	0
2	1:36	1:42	0	0	22	3:36	3:42	0	0
3	1:42	1:48	0	0	23	3:42	3:48	55	0.23
4	1:48	1:54	0	0	24	3:48	3:54	0	0
5	1:54	2:00	0	0	25	3:54	4:00	0	0
6	2:00	2:06	0	0	26	4:00	4:06	0	0
7	2:06	2:12	0	0	27	4:06	4:12	0	0
8	2:12	2:18	0	0	28	4:12	4:18	0	0
9	2:18	2:24	0	0	29	4:18	4:28	0	0
10	2:24	2:30	0	0	30	4:30	4:36	0	0
11	2:30	2:36	0	0	31	4:36	4:42	0	0
12	2:36	2:42	0	0	32	4:42	4:48	30	0.124
13	2:42	2:48	0	0	33	4:48	4:54	0	0
14	2:48	2:54	0	0	34	4:54	5:00	0	0
15	2:54	3:00	0	0	35	5:00	5:06	0	0
16	3:00	3:06	0	0	36				
17	3:06	3:12	0	0	37				
18	3:12	3:18	0	0	38				
19	3:18	3:24	0	0	39				
20	3:24	3:30	0	0	40				

Sketch Showing How Opacity Varied With Time:

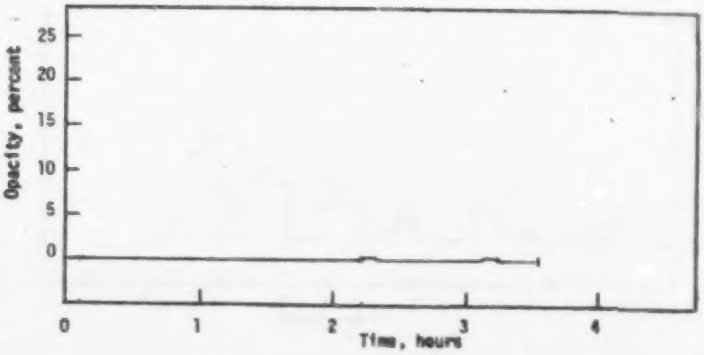


TABLE A-26

FACILITY C

Summary of Visible Emissions

Date: Sept. 18, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 20 feet

Location of Discharge: Stack

Height of Observation Point: Even with stacktop

Height of Point of Discharge: 15 feet above flat roof

Direction of Observer from Discharge Point: Roof, N.W. of stack

Description of Background: Sky

Description of Sky: 100% overcast

Wind Direction: N.W.

Wind Velocity: 0-5

Color of Plume: brown

Detached Plume: no

Duration of Observation: 2 Hours, 7 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	11:30	11:36	330	13.25	21	1:30	1:36	65	2.7
2	11:36	11:42	95	4.0	22				
3	11:42	11:48	5	0.2	23				
4	11:48	11:54	30	1.25	24				
5	11:54	12:00	10	0.417	25				
6	12:00	12:06	15	0.625	26				
7	12:06	12:12	0	0	27				
8	12:12	12:18	45	1.87	28				
9	12:18	12:24	120	5.0	29				
10	12:24	12:30	185	7.7	30				
11	12:30	12:36	235	9.8	31				
12	12:36	12:42	145	6.0	32				
13	12:42	12:48	165	6.87	33				
14	12:48	12:54	140	5.85	34				
15	12:54	1:00	40	1.66	35				
16	1:00	1:06	90	3.76	36				
17	1:06	1:12	35	1.46	37				
18	1:12	1:18	20	0.835	38				
19	1:18	1:24	0	0	39				
20	1:24	1:30	40	1.67	40				

Sketch Showing How Opacity Varied With Time:

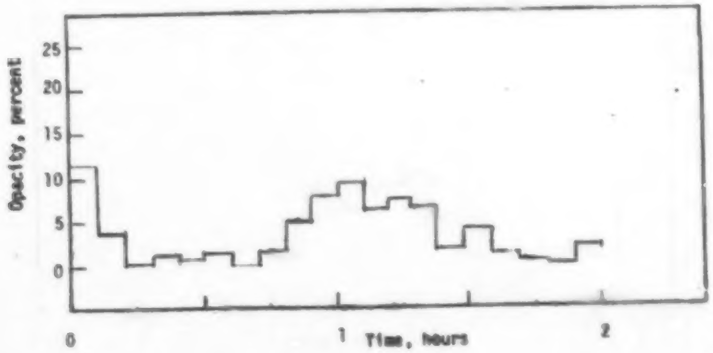


TABLE A-27

FACILITY C

Summary of Visible Emissions

Date: Sept. 18. 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 30 feet

Location of Discharge: Stack

Height of Observation Point: Even with stack top

Height of Point of Discharge: 15 feet

Direction of Observer from Discharge Point: North-West of Stack

Description of Background: Sky

Description of Sky: 100% overcast

Wind Direction: N.W.

Wind Velocity: 0-5 mph

Color of Plume: brown

Detached Plume: no

Duration of Observation: 2 Hours, 7 Minutes

SUMMARY OF AVERAGE OPACITY — SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	11:30	11:36	200	10.82	21				
2	11:36	11:42	130	5.42	22				
3	11:42	11:48	0	0	23				
4	11:48	11:54	20	0.83	24				
5	11:54	12:00	0	0	25				
6	12:00	12:06	0	0	26				
7	12:06	12:12	0	0	27				
8	12:12	12:18	40	1.66	28				
9	12:18	12:24	120	5.0	29				
10	12:24	12:30	235	9.8	30				
11	12:30	12:36	200	8.34	31				
12	12:36	12:42	150	6.27	32				
13	12:42	12:48	150	6.27	33				
14	12:48	12:54	120	5.0	34				
15	12:54	1:00	25	1.0	35				
16	1:00	1:06	90	3.75	36				
17	1:06	1:12	15	0.625	37				
18	1:12	1:18	15	0.625	38				
19	1:18	1:24	5	0.208	39				
20	1·24	1:30	50	2.08	40				

Sketch Showing How Opacity Varied With Time:

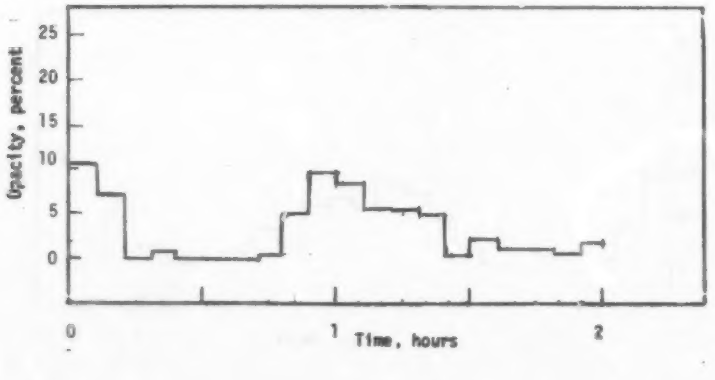


TABLE A-28

FACILITY C

Summary of Visible Emissions

Date: Sept. 18, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 20 feet

Location of Discharge: Stack

Height of Observation Point: Even with stack top

Height of Point of Discharge: 15 feet above flat roof

Direction of Observer from Discharge Point: Roof N.W. of stack

Description of Background: Sky

Description of Sky: 95% overcast

Wind Direction: N.W.

Wind Velocity: 0-5 mph

Color of Plume: Brown

Detached Plume: no

Duration of Observation: One Hour, 23 Minutes

SUMMARY OF AVERAGE OPACITY | SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	2:00	2:06	505	21	21				
2	2:06	2:12	45	1.8	22				
3	2:12	2:18	70	2.92	23				
4	2:18	2:24	15	0.625	24				
5	2:24	2:30	5	0.2	25				
6	2:30	2:36	105	4.4	26				
7	2:36	2:42	30	1.25	27				
8	2:42	2:48	125	5.21	28				
9	2:48	2:59	0	0	29				
10	2:59	3:00	140	13.15	30				
11	3:12	3:18	160	6.66	31				
12	3:18	3:24	175	7.3	32				
13	3:24	3:30	160	6.67	33				
14					34				
15					35				
16					36				
17					37				
18					38				
19					39				
20					40				

Sketch Showing How Opacity Varied With Time:

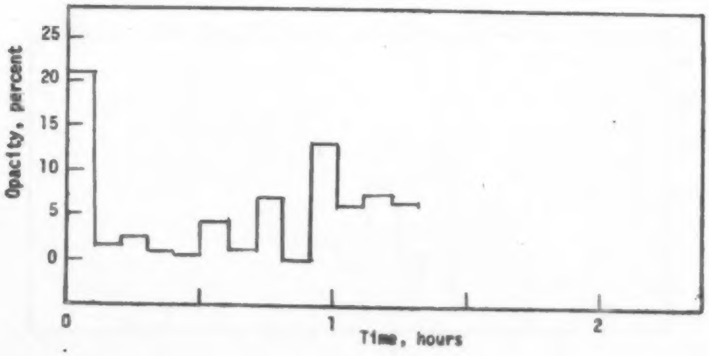


TABLE A-29

FACILITY C

Summary of Visible Emissions

Date: Sept. 18, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 30 feet

Location of Discharge: Stack

Height of Observation Point. even with stack top

Height of Point of Discharge: 15 feet

Direction of Observer from Discharge Point: 30 feet NW of stack

Description of Background: Sky

Description of Sky: 95% overcast

Wind Direction: N. W.

Wind Velocity: 0-5 mph

Color of Plume: brown

Detached Plume: no

Duration of Observation: One Hour, 23 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	2:00	2:06	505	21	21				
2	2:00	2:12	35	14.6	22				
3	2:12	2:18	70	29.2	23				
4	2:18	2:24	25	1.0	24				
5	2:24	2:30	0	0	25				
6	2:30	2:36	85	3.54	26				
7	2:36	2:42	20	8.36	27				
8	2:42	2:48	90	3.74	28				
9	2:48	2:54	0	0	29				
10	2:59	3:00	95	3.96	30				
11	2:30	3:06	305	12.7	31				
12	3:06	3:12	60	2.5	32				
13	3:12	3:18	115	4.8	33				
14	3:18	3:24	165	6.87	34				
15					35				
16					36				
17					37				
18					38				
19					39				
20					40				

Sketch Showing How Opacity Varied With Time:

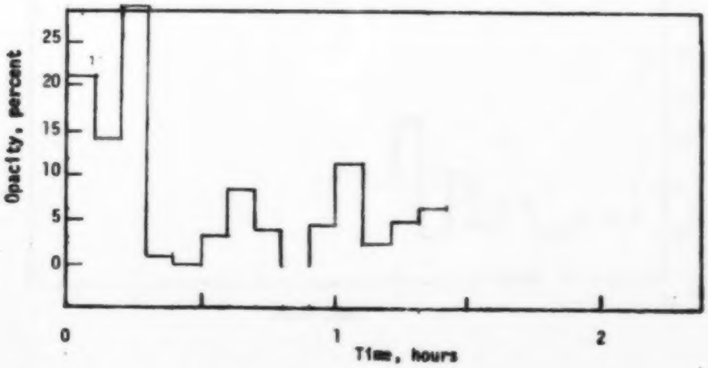


TABLE A-30

FACILITY C

Summary of Visible Emissions

Date: Sept. 19, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Distance from Observer to Discharge Point: 30 feet

Location of Discharge: Stack

Height of Observation Point: 20 feet above basis of stack

Height of Point of Discharge: 15 feet above flat roof

Direction of Observer from Discharge Point: 30 feet Roof, east of stack

Description of Background: Clear and Sunny

Description of Sky: South East

Wind Direction: brown

Wind Velocity: 0-5 mph

Color of Plume: 2 hours 18 minutes

Detached Plume: no

Duration of Observation: 2 Hours, 12 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	8:30	8:36	290	12.1	21	10:30	10:36	25	1.05
2	8:36	8:42	5	0.2	22	10:36	10:42	15	0.627
3	8:42	8:48	0	0	23	10:42	10:48	0	0
4	8:48	8:54	0	0	24				
5	8:54	9:00	0	0	25				
6	9:00	9:06	0	0	26				
7	9:06	9:12	40	1.65	27				
8	9:12	9:18	40	1.65	28				
9	9:18	9:24	80	3.3	29				
10	9:24	9:30	5	0.2	30				
11	9:30	9:36	60	2.5	31				
12	9:36	9:42	50	2.08	32				
13	9:42	9:48	75	3.13	33				
14	9:48	9:54	20	0.83	34				
15	9:54	10:00	80	3.33	35				
16	10:00	10:06	315	13.12	36				
17	10:06	10:12	310	12.8	37				
18	10:12	10:18	730	32.5	38				
19	10:18	10:24	135	5.63	39				
20	10:24	10:30	10	0.416	40				

Sketch Showing How Opacity Varied With Time:

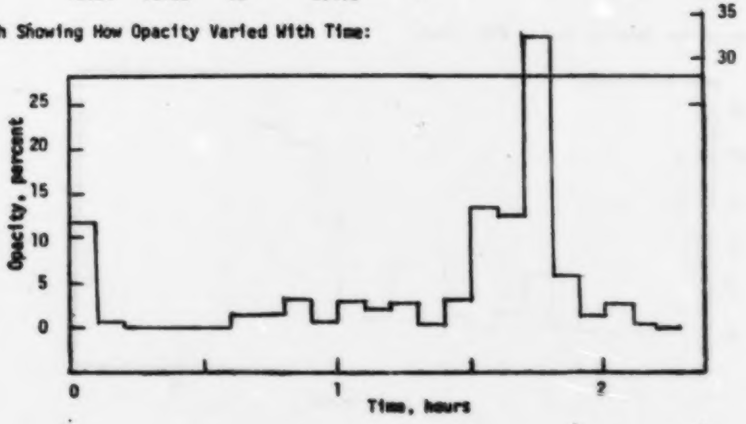


TABLE A-31

FACILITY C

Summary of Visible Emissions

Date: Sept. 19, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Particulates

Location of Discharge: Stack

Height of Point of Discharge: 15 feet

Description of Background: Sky

Description of Sky: Clear and Sunny

Wind Direction: South East

Color of Plume: brown

Duration of Observation: 2 Hours, 12 Minutes

Distance from Observer to Discharge Point: 30 feet

Height of Observation Point: even with base of stack

Direction of Observer from Discharge Point: 30 feet east of stack

Wind Velocity: 0-5 mph

Detached Plume: no

SUMMARY OF AVERAGE OPACITY | SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	8:30	8:36	245	10.2	21	10:36	10:42	0	0
2	8:36	8:42	0	0	22	10:42	10:48	0	0
3	8:42	8:48	0	0	23				
4	8:48	8:54	0	0	24				
5	8:54	9:00	0	0	25				
6	9:00	9:06	35	1.45	26				
7	9:06	9:12	15	6.25	27				
8	9:12	9:18	60	2.5	28				
9	9:18	9:24	0	0	29				
10	9:24	9:30	40	1.66	30				
11	9:30	9:36	70	2.91	31				
12	9:42	9:48	55	2.39	32				
13	9:48	9:54	20	0.837	33				
14	9:54	10:00	75	3.11	34				
15	10:00	10:06	335	12.96	35				
16	10:06	10:12	500	20.08	36				
17	10:12	10:18	530	22.1	37				
18	10:18	10:24	140	23.3	38				
19	10.24	10:30	5	0	39				
20	10:30	10:36	5	0	40				

Sketch Showing How Opacity Varied With Time:

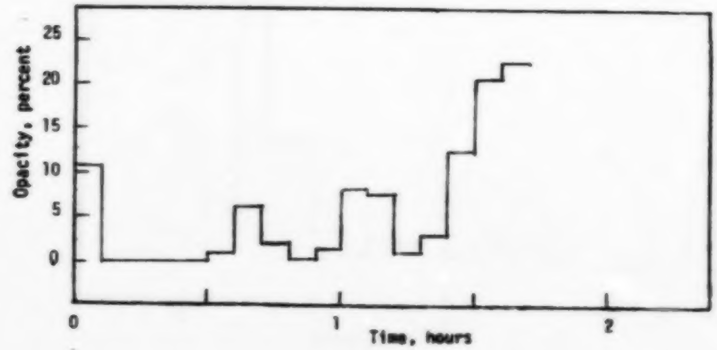


TABLE A-32

FACILITY D

Summary of Visible Emissions

Date: October 1, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Dust

Distance from Observer to Discharge Point: 50 Feet

Location of Discharge: Baghouse Outlet

Height of Observation Point: Ground Level

Height of Point of Discharge: 20 Feet

Direction of Observer from Discharge Point: South

Description of Background: Sky

Description of Sky: Overcast

Wind Direction: East

Wind Velocity: 3 to 5

Color of Plume: White

Detached Plume: No

Duration of Observation: 87 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	3:20	3:26	0	0	21				
2	3:26	3:32	0	0	22				
3	3:32	3:38	0	0	23				
4	3:38	3:44	0	0	24				
5	3:44	3:50	0	0	25				
6	3:50	3:56	0	0	26				
7	3:56	4:02	0	0	27				
8	4:02	4:08	0	0	28				
9	4:08	4:14	0	0	29				
10	4:14	4:20	0	0	30				
11	4:20	4:26	0	0	31				
12	4:26	4:32	0	0	32				
13	4:32	4:38	0	0	33				
14	4:38	4:44	0	0	34				
15	4:44	4:47	0	0	35				
16					36				
17					37				
18					38				
19					39				
20					40				

Sketch Showing How Opacity Varied With Time:

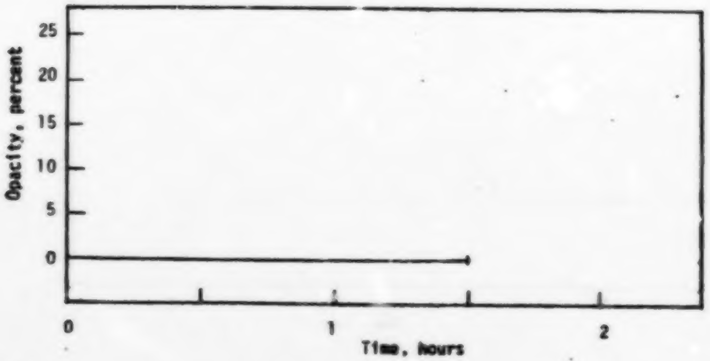


TABLE A-33

FACILITY D

Summary of Visible Emissions

Date: October 1, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Furnace Roof Exhaust   Distance from Observer to Discharge Point: 90 Feet

Location of Discharge: Furnace Roof Exhaust   Height of Observation Point: Ground Level

Height of Point of Discharge: 80 Feet   Direction of Observer from Discharge Point: South

Description of Background: Sky

Description of Sky: Overcast - partly cloudy

Wind Direction: East   Wind Velocity: 3 to 5

Color of Plume: White   Detached Plume: No

Duration of Observation: 120 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	3:20	3:26	120	5.0	21				
2	3:26	3:32	120	5.0	22				
3	3:32	3:38	120	5.0	23				
4	3:38	3:44	120	5.0	24				
5	3:44	3:50	120	5.0	25				
6	3:50	3:56	120	5.0	26				
7	3:56	4:02	120	5.0	27				
8	4:02	4:08	120	5.0	28				
9	4:08	4:14	175	7.3	29				
10	4:14	4:20	120	5.0	30				
11	4:20	4:26	120	5.0	31				
12	4:26	4:32	120	5.0	32				
13	4:32	4:38	120	5.0	33				
14	4:38	4:44	120	5.0	34				
15	4:44	4:50	120	5.0	35				
16	4:50	4:56	120	5.0	36				
17	4:56	5:02	120	5.0	37				
18	5:02	5:08	120	5.0	38				
19	5:08	5:14	120	5.0	39				
20	5:14	5:20	120	5.0	40				

Sketch Showing How Opacity Varied With Time:

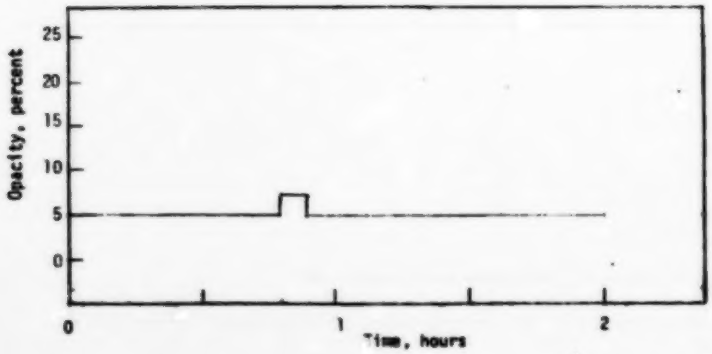


TABLE A-34

FACILITY D

Summary of Visible Emissions

Date: October 2, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Dust

Distance from Observer to Discharge Point: 50 Feet

Location of Discharge: Baghouse Outlet

Height of Observation Point: Ground Level

Height of Point of Discharge: 20 Feet

Direction of Observer from Discharge Point: South

Description of Background: Sky

Description of Sky: Partly Cloudy

Wind Direction: South

Wind Velocity: 20 to 30

Color of Plume: White

Detached Plume: No

Duration of Observation: 210 Minutes

SUMMARY OF AVERAGE OPACITY | SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1 A.M.	9:25	9:31	0	0	21	4:04	4:10	0	0
2	9:31	9:37	0	0	22	4:10	4:16	0	0
3	9:37	9:55	No Readings		23	4:16	4:22	0	0
4	9:55	10:01	0	0	24	4:22	4:28	0	0
5	10:01	10:07	0	0	25	4:28	4:34	0	0
6	10:07	10:13	0	0	26	4:34	4:38	0	0
7	10:13	10:15	0	0	27	4:38	4:48	No Readings	
8	10:15	10:21	No Readings		28	4:48	4:54	0	0
9	10:21	10:27	10	0.4	29	4:54	5:00	0	0
10	10:27	10:39	No Readings		30	5:00	5:06	0	0
11	10:39	10:41	5	0.6	31	5:06	5:12	0	0
12 P.M.	3:10	3:16	0	0	32	5:12	5:18	0	0
13	3:16	3:22	0	0	33	5:18	5:24	0	0
14	3:22	3:28	0	0	34	5:24	5:30	0	0
15	3:28	3:34	0	0	35	5:30	5:36	0	0
16	3:34	3:40	0	0	36	5:36	5:42	0	0
17	3:40	3:46	0	0	37	5:42	5:48	0	0
18	3:46	3:52	0	0	38	5:48	5:54	0	0
19	3:52	3:58	0	0	39	5:54	6:00	0	0
20	3:58	4:04	0	0	40	6:00	6:06	0	0
					41	6:06	6:10	0	0

Sketch Showing How Opacity Varied With Time:

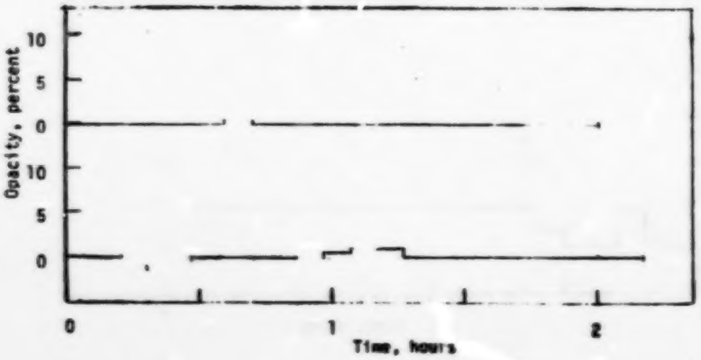


TABLE A-35

FACILITY D

Summary of Visible Emissions

Date: October 2, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Dust

Distance from Observer to Discharge Point: 90 Feet

Location of Discharge: Furnace Roof Exhaust

Height of Observation Point: Ground Level

Height of Point of Discharge: 80 Feet

Direction of Observer from Discharge Point: South

Description of Background: Sky

Description of Sky: Clear, Scattered Clouds

Wind Direction: South

Wind Velocity: 20 to 30

Color of Plume: White

Detached Plume: No

Duration of Observation: 120 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	9:25	9:31	5	0.2	21				
2	9:31	9:37	10	0.4	22				
3	9:37	9:43	110	4.6	23				
4	9:43	9:49	0	0	24				
5	9:49	9:55	0	0	25				
6	9:55	10:01	65	2.7	26				
7	10:01	10:07	120	5.0	27				
8	10:07	10:13	120	5.0	28				
9	10:13	10:19	120	5.0	29				
10	10:19	10:25	120	5.0	30				
11	10:25	10:31	120	5.0	31				
12	10:31	10:37	120	5.0	32				
13	10:37	10:43	120	5.0	33				
14	10:43	10:49	120	5.0	34				
15	10:49	10:55	120	5.0	35				
16	10:55	11:01	120	5.0	36				
17	11:01	11:07	120	5.0	37				
18	11:07	11:13	120	5.0	38				
19	11:13	11:19	120	5.0	39				
20	11:19	11:25	120	5.0	40				

Sketch Showing How Opacity Varied With Time:

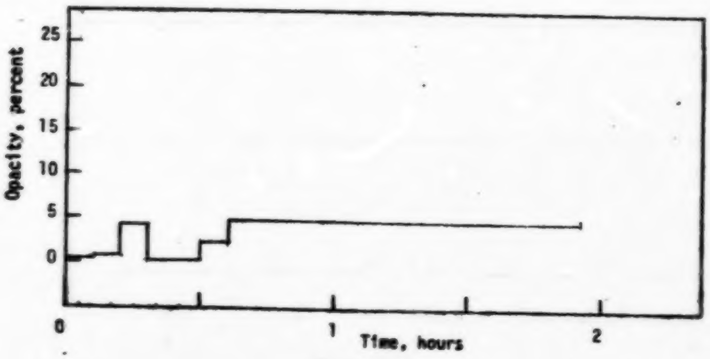


TABLE A-36

FACILITY D

Summary of Visible Emissions

Date: October 2, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Dust

Distance from Observer to Discharge Point: 90 Feet

Location of Discharge: Furnace Roof Exhaust

Height of Observation Point: Ground Level

Height of Point of Discharge: 80 Feet

Direction of Observer from Discharge Point: South

Description of Background: Sky

Description of Sky: Clear, Scattered Clouds

Wind Direction: South

Wind Velocity: 20 to 30

Color of Plume: White

Detached Plume: No

Duration of Observation: 180 Minutes

SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	3:10	3:16	120	5.0	21	5:10	5:16	120	5.0
2	3:16	3:22	120	5.0	22	5:16	5:22	120	5.0
3	3:22	3:28	120	5.0	23	5:22	5:28	120	5.0
4	3:28	3:34	120	5.0	24	5:28	5:34	120	5.0
5	3:34	3:40	120	5.0	25	5:34	5:40	120	5.0
6	3:40	3:46	120	5.0	26	5:40	5:46	120	5.0
7	3:46	3:52	120	5.0	27	5:46	5:52	120	5.0
8	3:52	3:58	120	5.0	28	5:52	5:58	120	5.0
9	3:58	4:04	120	5.0	29	5:58	6:04	120	5.0
10	4:04	4:10	120	5.0	30	6:04	6:10	120	5.0
11	4:10	4:16	120	5.0	31				
12	4:16	4:22	120	5.0	32				
13	4:22	4:28	150	6.3	33				
14	4:28	4:34	140	6.8	34				
15	4:34	4:40	120	5.0	35				
16	4:40	4:46	165	6.9	36				
17	4:46	4:52	150	6.3	37				
18	4:52	4:58	120	5.0	38				
19	4:58	5:04	120	5.0	39				
20	5:04	5:10	120	5.0	40				

Sketch Showing How Opacity Varied With Time:

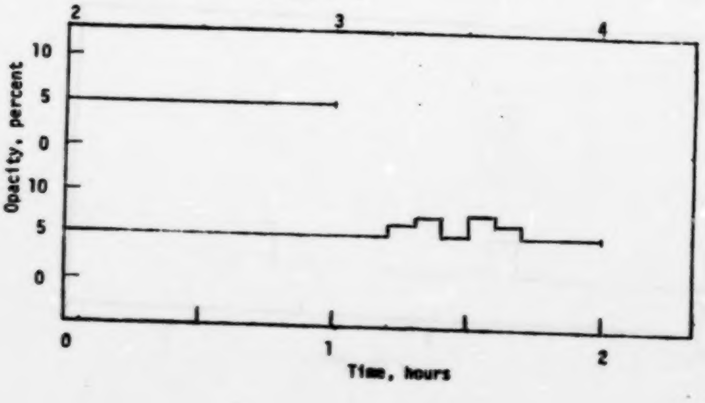


TABLE A-37

FACILITY D

Summary of Visible Emissions

Date: October 3, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Dust

Distance from Observer to Discharge Point: 50 Feet

Location of Discharge: Baghouse Outlet

Height of Observation Point: Ground Level

Height of Point of Discharge: 20 Feet

Direction of Observer from Discharge Point: South

Description of Background: Sky

Description of Sky: Partly Cloudy

Wind Direction: Southwest

Wind Velocity: 20 to 35

Color of Plume: White

Detached Plume: No

Duration of Observation: 82 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	9:18	9:24	0	0	21				
2	9:24	9:30	0	0	22				
3	9:30	9:36	0	0	23				
4	9:36	9:42	0	0	24				
5	9:42	9:48	0	0	25				
6	9:48	9:54	0	0	26				
7	9:54	10:00	0	0	27				
8	10:00	10:06	100	4.2	28				
9	10:06	10:12	20	0.8	29				
10	10:12	10:18	0	0	30				
11	10:18	10:24	0	0	31				
12	10:24	10:29	0	0	32				
13	10:29	10:52	No Readings		33				
14	10:52	10:58	120	5.0	34				
15	10:58	11:03	100	5.0	35				
16					36				
17					37				
18					38				
19					39				
20					40				

Sketch Showing How Opacity Varied With Time:

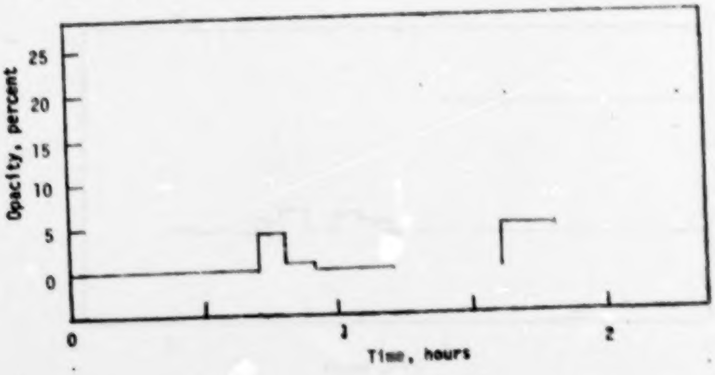


TABLE A-38

FACILITY D

Summary of Visible Emissions

Date: October 3, 1974

Type of Plant: Gray Iron Foundry

Type of Discharge: Dust

Distance from Observer to Discharge Point: 90 Feet

Location of Discharge: Furnace Roof Exhaust

Height of Observation Point: Ground Level

Height of Point of Discharge: 80 Feet

Direction of Observer from Discharge Point: South

Description of Background: Sky

Description of Sky: Partly Cloudy

Wind Direction: Southwest

Wind Velocity: 20 to 35

Color of Plume: White

Detached Plume: No

Duration of Observation: 63 Minutes

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	9:03	9:09	0	0	21				
2	9:09	9:15	20	0.8	22				
3	9:15	9:18	20	1.7	23				
4	9:18	10:47	No Readings		24				
5	10:47	10:53	120	5.0	25				
6	10:53	10:57	80	5.0	26				
7	10:57	11:08	No Readings		27				
8	11:08	11:14	120	5.0	28				
9	11:14	11:20	120	5.0	29				
10	11:20	11:26	120	5.0	30				
11	11:26	11:32	120	5.0	31				
12	11:32	11:38	120	5.0	32				
13	11:38	11:44	120	5.0	33				
14	11:44	11:46	40	5.0	34				
15					35				
16					36				
17					37				
18					38				
19					39				
20					40				

Sketch Showing How Opacity Varied With Time:

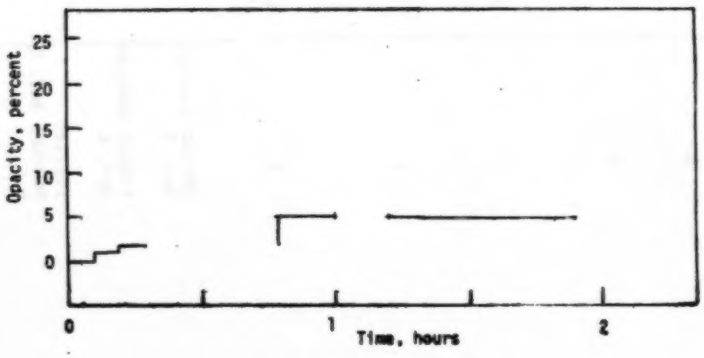


TABLE A-39. TEST RESULTS ON FABRIC FILTERS INSTALLED ON STEEL-PRODUCING ELECTRIC ARC FURNACES

Plant	Outlet Loadings mg/dscm	Control device Type	Furnace Capacity Mg	Furnace heat duration hrs	Measuring Method
A	9.17, 5.73 6.87, 36.68	Fabric filter	27.2	2	ASME
B	4.58, 6.87	Fabric filter	29.92	2	ASME
C	5.73, 2.8 8.71	Fabric filter	33.18	4	EPA 5
D	6 to 20 14 tests, average .003	Fabric filter	20 - 22	2.5	VDI
E	1 - 4	Fabric filter	Two furnaces 7 and 4 on one control device	not specified	VDI
F	6.63	Fabric filter	30 31.2 two consequtive heats	each 2 hours test runs for 4 hours	EPA 5
German Sources Ref. 3	2 - 20	Fabric filter	not specified	not specified	VDI
French Sources Ref. 4	5 to 15	Fabric filter	8	not specified	VDI
Italian Sources Ref. 5 5	4 to 12	Fabric filter	not specified	not specified	VDI

TABLE A-40. TEST RESULTS ON FABRIC FILTERS INSTALLED ON STEEL-PRODUCING ELECTRIC ARC FURNACES

Plant	Outlet Loadings gr/dscf	Control Device Type	Furnace Capacity short tons	Furnace heat duration hrs	Measuring Method
A	0.004 0.0025 0.003 0.0064	Fabric filter	30	2	ASME
B	0.002 0.003	Fabric filter	33	2	ASME
C	0.00225 0.001223 0.0038	Fabric filter	36.5	4	EPA 5
D	0.0026 0.0087 14 tests, average 7	Fabric filter	22 - 24.2	2.5	VDI
E	0.00043 0.00174	Fabric filter	Two furnaces 7.7 and 4.4 on one control device	not specified	VDI
F	0.0029	Fabric filter	30 31.2 two consequtive heats	each 2 hours test runs for 4 hours	EPA 5
German Sources Ref. 3	0.00087 0.0087	Fabric filter	not specified	not specified	VDI
French Sources Ref. 4	0.00218 0.0065	Fabric filter	8.8	not specified	VDI
Italian Sources Ref. 5	0.00174 0.00522	Fabric filter	not specified	not specified	VDI

TABLE A-41

FACILITY B

Summary of Visible Emissions - Roof Vents

Heat No.	Process Condition	Six Minute Average Start time	Vent A	Vent B
1206	Charge	9:29	1.2	1.5
	Back-charge	10:31	8.1	9.6
	Tap	11:59	12.9	16.7
1207	Charge	12:10	1.9	0.4
	Back-charge	12:57	5.6	4.8
	Tap	14:22	8.3	16.0

NOTE: No visible emissions were noted during the remainder of the two heats observed.

Heat No. 1206 & 1207 were observered on July 14, 1976.

TABLE A-42

FACILITY B

SUMMARY OF VISIBLE EMISSIONS
Heat #1206

Date: July 14, 1976

Type of Plant: Steel Foundry

Type of Discharge: Electric Arc Furnace

Location of Discharge: Baghouse Outlet

Height of Point of Discharge: ≈10-15 meters

Description of Background: Sky

Description of Sky: varied - blue to overcast

Wind Direction: ----

Color of Plume: gray-white

Interference of Steam Plume:

Duration of Observation:

Distance from Observer to Discharge Point:

Height of Observation Point: ground level

Direction of Observer from Discharge Point:

Wind Velocity:

Detached Plume:

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
1	9:29		5	0.2
2	9:35		5	0.2
3	9:41		20	0.8
4	9:47		0	0.0
5	9:53		15	0.6
6	9:59		0	0.0
7	10:05		85	3.5
8	10:11		96	4.0
9	10:17		145	6.0
10	10:23		545	21.9
11	10:29		290	12.1
12	10:35		55	2.3
13	10:41		0	0.0
14	10:47		10	0.4
15	10:53		65	2.7
16	10:59		60	2.5
17	11:05		155	6.5
18	11:11		150	6.3
19	11:17		130	5.4
20	11:23		190	7.9

SUMMARY OF AVERAGE OPACITY

	Time		Opacity	
Set Number	Start	End	Sum	Average
21	11:29		375	15.6
22	11:35		15	0.6
23	11:41		50	2.1
24	11:47		0	0.0
25	11:53		0	0.0
26	11:59*		0	0.0

[*] Last set consists of 20 readings

Sketch Showing How Opacity Varied With Time:

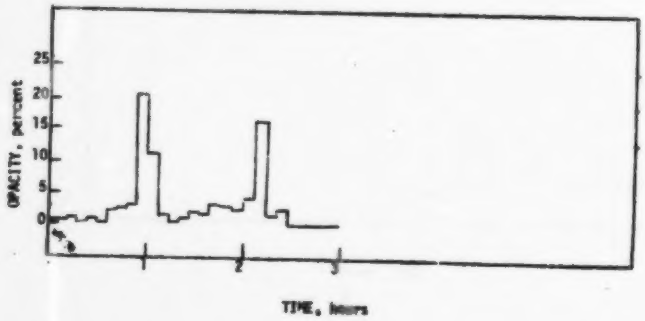


TABLE A-43

FACILITY 8

SUMMARY OF VISIBLE EMISSIONS
Heat #1207

Date: July 14, 1976

Type of Plant: Steel Foundry

Type of Discharge: Electric Arc Furnace

Distance from Observer to Discharge Point:

Location of Discharge: Baghouse Outlet

Height of Point of Discharge: ≈10-15 meters

Height of Observation Point: ground level

Description of Background: Sky

Direction of Observer from Discharge Point:

Description of Sky: varied - blue to overcast

Wind Direction:

Wind Velocity:

Color of Plume: gray-white

Detached Plume:

Interference of Steam Plume:

Duration of Observation:

SUMMARY OF AVERAGE OPACITY

	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	12:10		90	3.8	21	14:10		0	0.0
2	12:16		30	1.2	22	14:16		0	0.0
3	12:22		90	3.8	23	14:22	14:25:30	0	0.0
4	12:28		40	1.7	24				
5	12:34		25	1.0	25				
6	12:40		100	4.2	26				
7	12:46		135	5.6	27				
8	12:52		75	3.1	28				
9	12:58		20	0.8	29				
10	13:04		0	0.0	30				
11	13:10		0	0.0	31				
12	13:16		0	0.0	32				
13	13:22		75	3.1	33				
14	13:28		45	1.9	34				
15	13:34		50	2.1	35				
16	13:40		30	1.2	36				
17	13:46		5	0.2	37				
18	13:52		205	8.5	38				
19	13:58		285	11.9	39				
20	14:04		30	1.2	40				

Last data set consists of 14 consecutive readings.

Sketch Showing How Opacity Varied With Time:

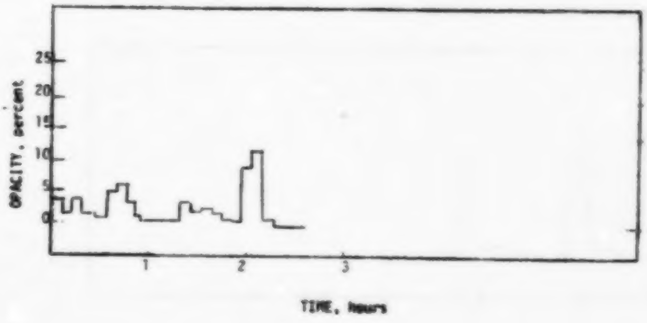


TABLE A-44

FACILITY B

SUMMARY OF VISIBLE EMISSIONS

Date: Sept. 28, 1976
Type of Plant: Steel Foundry Electric Arc Furnace
Type of Discharge: Stack
Location of Discharge: Baghouse Outlet
Height of Point of Discharge: 10-15 meters
Description of Background: Sky
Description of Sky: Partly cloudy
Wind Direction: Variable
Color of Plume:
Interference of Steam Plume: None
Duration of Observation: 90 minutes
Distance from Observer to Discharge Point: Until 11:00 am 200 feet, then 200 feet
Height of Observation Point: ground
Direction of Observer from Discharge Point: south of stack
Wind Velocity: not recorded, but high
Detached Plume: No

SUMMARY OF AVERAGE OPACITY				SUMMARY OF AVERAGE OPACITY			
	Time		Opacity		Time		Opacity
Set Number	Start	End	Average	Set Number	Start	End	Average
1	10:05		0				
2	10:11		0				
3	10:17		0				
4	10:23		0				
5	10:29		0				
6	10:35		0				
7	10:41		0				
8	10:47		0				
9	10:53		0				
10	10:59		0				
11	11:05		0				
12	11:11		0				
13	11:17		0				
14	11:23		0				
15	11:29		0				
16	11:35		0				
17							
18							
19							
20							

Sketch Showing How Opacity Varied With Time:

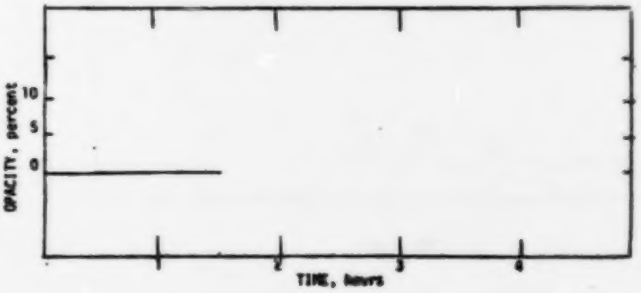


TABLE A-45

FACILITY C

SUMMARY OF VISIBLE EMISSIONS
Heat # E1-3256

Date: July 22, 1976

Type of Plant: Steel Foundry

Type of Discharge: Electric Arc Furnace

Location of Discharge: Roof vents

Height of Point of Discharge: ≈25 meters

Description of Background: Building

Description of Sky: overcast

Wind Direction: variable

Color of Plume:

Interference of Steam Plume:

Duration of Observation:

Distance from Observer to Discharge Point: ≈45 meters

Height of Observation Point: ≈10 meters

Direction of Observer from Discharge Point: ≈East

Wind Velocity:

Detached Plume:

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	7:56		90	3.8	21	9:56		5	0.2
2	8:02		25	1.0	22	10:02		5	0.2
3	8:08		110	4.6	23	10:08		0	0.0
4	8:14		0	0.0	24	10:14		0	0.0
5	8:20		0	0.0	25	10:20		0	0.0
6	8:26		0	0.0	26	10:26		25	1.0
7	8:32		5	0.2	27	10:32		120	5.0
8	8:38		0	0.0	28	10:38		165	6.9
9	8:44		0	0.0	29	10:44		35	1.5
10	8:50		0	0.0	30	10:50		0	0.0
11	8:56		5	0.2	31	10:56		0	0.0
12	9:02		0	0.0	32	11:02		85	3.5
13	9:08		0	0.0	33	11:08		0	0.0
14	9:14		0	0.0	34	11:14		235	9.8
15	9:20		0	0.0	35	11:20	11:26	0	0.0
16	9:26		10	0.4	36				
17	9:32		0	0.0	37				
18	9:38		10	0.4	38				
19	9:44		25	1.0	39				
20	9:50		135	5.6	40				

Sketch Showing How Opacity Varied With Time:

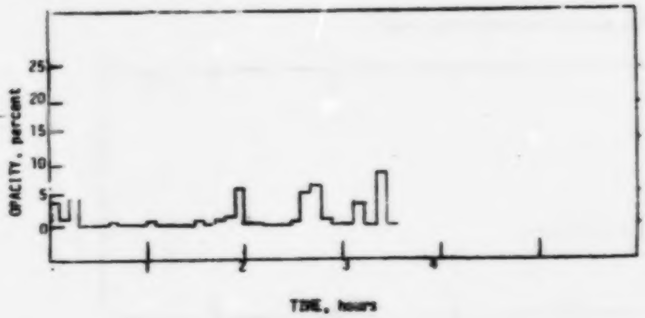


TABLE A-46

FACILITY C

SUMMARY OF VISIBLE EMISSIONS
Heat # ET-3251

Date: July 21, 1976

Type of Plant: Steel Foundry Electric Arc Furnace

Type of Discharge: Roof Vents

Location of Discharge: Roof of Building

Height of Point of Discharge: ≈ 25 meters

Description of Background: Building

Description of Sky: overcast

Wind Direction: variable

Color of Plume:

Interference of Steam Plume:

Duration of Observation:

Distance from Observer to Discharge Point: ≈46 meters

Height of Observation Point: ≈10 meters

Direction of Observer from Discharge Point: ≈ West

Wind Velocity:

Detached Plume:

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	7:51		30	1.2	21				
2	7:57		0	0.0	22				
3	8:03	8:09	0	0.0	23				
4	8:20		0	0.0	24				
5	8:26		0	0.0	25				
6	8:32		0	0.0	26				
7	8:38		0	0.0	27				
8	8:44		30	1.2	28				
9	8:50		0	0.0	29				
10	8:56	9:02	10	0.4	30				
11	9:13	9:19	20	0.8	31				
12	9:19		180	7.5	32				
13	9:25		165	6.9	33				
14	9:31		115	4.8	34				
15	9:37		40	1.7	35				
16	9:43		210	8.8	36				
17	9:49	9:55	115	4.8	37				
18	9:55				38				
19					39				
20					40				

Sketch Showing How Opacity Varied With Time:

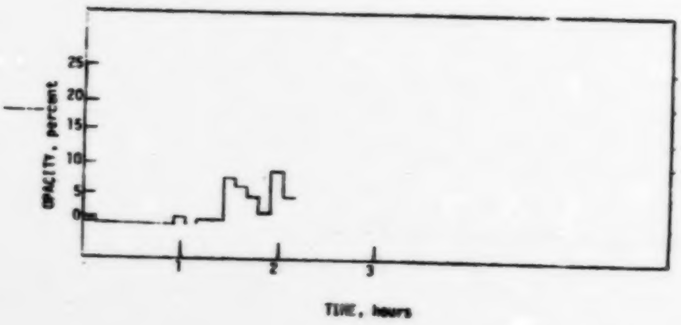


TABLE A-47

FACILITY C

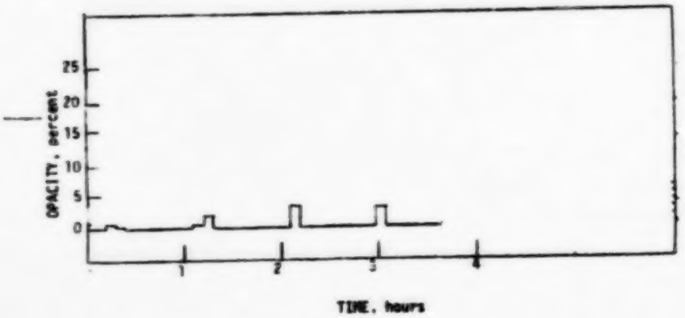
SUMMARY OF VISIBLE EMISSIONS
Heat # E1-3251

Date: July 21, 1976
Type of Plant: Steel Foundry Electric Arc Furnace
Type of Discharge: Stack
Location of Discharge: Baghouse Outlet
Height of Point of Discharge: ≈20 meters
Description of Background: sky
Description of Sky: overcast
Wind Direction:
Color of Plume:
Interference of Steam Plume:
Duration of Observation:

Distance from Observer to Discharge Point: ≈30 meters
Height of Observation Point: ground
Direction of Observer from Discharge Point: ≈ Northeast
Wind Velocity:
Detached Plume:

SUMMARY OF AVERAGE OPACITY					SUMMARY OF AVERAGE OPACITY				
	Time		Opacity			Time		Opacity	
Set Number	Start	End	Sum	Average	Set Number	Start	End	Sum	Average
1	6:18		0	0.0	21	8:18		0	0.0
2	6:24		0	0.0	22	8:24		75	3.1
3	6:30		15	0.6	23	8:30		0	0.0
4	6:36		80	3.3	24	8:36		0	0.0
5	6:42		0	0.0	25	8:42		0	0.0
6	6:48		0	0.0	26	8:48		0	0.0
7	6:54		0	0.0	27	8:54		0	0.0
8	7:00		0	0.0	28	9:00		0	0.0
9	7:06		0	0.0	29	9:06		0	0.0
10	7:12		0	0.0	30	9:12		0	0.0
11	7:18		0	0.0	31	9:18		65	2.7
12	7:24		10	0.4	32	9:24		0	0.0
13	7:30		55	2.3	33	9:30		0	0.0
14	7:36		0	0.0	34	9:36		0	0.0
15	7:42		0	0.0	35	9:42		0	0.0
16	7:48		0	0.0	36	9:48		0	0.0
17	7:54		0	0.0	37	9:54		0	0.0
18	8:00		0	0.0	38				
19	8:06		0	0.0	39				
20	8:12		0	0.0	40				

Sketch Showing How Opacity Varied With Time:



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APPENDIX B

DETAILED COST ANALYSIS FOR FURNACES PRODUCING IRON CASTINGS

TABLE B-1. SUMMARY OF CONTROL COSTS FOR 3.6 megagram/hour MODEL PLANT PRODUCING GRAY IRON (SINGLE-FURNACE SHOP)

Evacuation System	Side Draft Only	Side Draft Only	Side Draft Only	Side Draft Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Side Draft
Process Constraint	--	--	Clean Scrap	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Preheater[(1)]	Briquetter[(2)]	--	--	--
Pollutant Removal efficiency, %	87	87	92	92	96	97.5	95
Model New Facilities							
Installed Capital ($)	198,000	538,000	292,300	357,000	236,000[(3)]	280,000[(4)]	1,104,000
Direct Operating Cost ($/yr)	9,170	49,000	16,200	32,300	9,500	10,000	56,800
Capital Charges ($/Yr)	33,400	92,300	50,100	61,200	40,400	48,000	189,000
Net Annualized Costs ($/Yr)	42,570	141,300	66,300	93,500	49,900	58,000	245,800
Controlled Emissions (1000 Kg/Yr)	40.60	40.60	42.82	42.82	44.68	45.36	44.36
Cost Per Kg Controlled ($/Kg)	1.05	3.48	1.55	2.18	1.11	1.28	5.54
Model Existing Facilities							
Installed Capital ($)	198,000	592,000	232,300	357,000	260,000	325,000	1,470,000
Direct Operating Costs ($/Yr)	9,170	49,000	16,200	32,300	9,500	10,000	56,800
Capital Charges ($/Yr)	33,400	102,000	50,100	61,200	44,600	55,700	252,000
Net Annualized Costs ($/Yr)	42,570	151,000	66,300	93,500	54,100	65,700	308,800
Controlled Emissions (1000 Kg/Yr)	40.60	40.60	42.82	42.82	44.68	45.36	44.36
Cost per Kg Controlled ($/Kg)	1.05	3.72	1.55	2.18	1.21	1.45	5.96

(1) Capital cost of $94,300 and direct operating costs of $7000 - Reference 1, Section 4.

(2) Capital cost of $159,000 and direct operating costs of $23,100 - Reference 6, Section 4.

(3) Includes purchase cost of $20,000 for special hoods to capture charging and melting emissions - Reference 3, Section 4.

(4) Includes purchase cost of $20,000 for special hoods (3) and $40,000 for hood and enclosure on tapping area - Reference 7, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4

TABLE B-2. SUMMARY OF CONTROL COSTS FOR 7.3 megagram/hour MODEL PLANT PRODUCING GRAY IRON (TWO-FURNACE SHOP)

Evacuation System	Side Draft Only	Side Draft Only	Side Draft Only	Side Draft Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Side Draft
Process Constraint	--	--	Clean Scrap	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse⁽¹⁾	Baghouse⁽²⁾	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Pre-Heater	Briquetter	--	--	--
Pollutant Removal Efficiency %	87	87	92	92	96	97.5	95
Model New Facilities							
Installed Capital ($)	400,000	790,000	517,000	559,000	476,000	570,000	1,300,000
Direct Operating Cost ($/yr)	19,800	85,700	33,800	66,000	20,600	21,500	64,800
Capital Charges ($/yr)	68,600	135,000	88,700	95,900	81,600	97,800	223,000
Net Annualized Costs ($/yr)	88,400	220,700	123,000	162,000	102,000	119,300	287,800
Controlled Emissions (1000 Kg/yr)	81.20	81.2	85.6	85.6	89.5	90.5	88.7
Cost Per Kg Controlled ($/Kg)	1.09	2.72	1.44	1.89	1.14	1.32	3.24
Model Existing Facilities							
Installed Capital ($)	400,000	870,000	517,000	559,000	524,000	660,000	1,800,000
Direct Operating Costs ($/yr)	19,800	85,700	33,800	66,000	20,600	21,500	64,800
Capital Charges ($/yr)	68,600	149,000	88,700	95,900	89,900	113,000	309,000
Net Annualized Costs ($/yr)	88,400	234,700	123,000	162,000	110,500	134,500	374,000
Controlled Emissions (1000 Kg/yr)	81.2	81.2	85.6	85.6	89.5	90.5	88.7
Cost per Kg Controlled ($/Kg)	1.09	2.89	1.44	1.89	1.23	1.49	4.22

(1) Capital cost of $117,000 and direct operating cost of $14,000 - Reference 1, Section 4.

(2) Capital cost of $159,000 and direct operating cost of $46,200 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

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TABLE B-3. SUMMARY OF CONTROL COSTS FOR 9.1 megagram/hour MODEL PLANT PRODUCING GRAY IRON (SINGLE-FURNACE SHOP)

Evacuation System	Side Draft Only	Side Draft Only	Side Draft Only	Side Draft Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Side Draft
Process Constraint	--	--	Clean Scrap	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse (1)	Baghouse (2)	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Pre-Heater	Briquetter	--	--	--
Pollutant Removal Efficiency %	87	87	92	92	96	97.5	95
Model New Facilities							
Installed Capital ($)	317,000	686,000	434,000	476,000	370,000	448,000	1,210,000
Direct Operating Cost ($/yr)	15,450	77,000	28,400	124,000	16,100	16,800	64,400
Capital Charges ($/yr)	54,400	118,000	74,400	81,600	63,400	76,800	208,000
Net Annualized Costs ($/yr)	69,900	195,000	102,800	205,600	79,500	93,600	272,400
Controlled Emissions (1000 Kg/yr)	121.8	121.8	128.5	128.5	134.3	136.1	133.1
Cost Per Kg Controlled ($/Kg)	0.57	1.60	0.80	1.60	0.59	0.69	2.05
Model Existing Facilities							
Installed Capital ($)	317,000	755,000	434,000	476,000	409,000	520,000	1,610,000
Direct Operating Costs ($/yr)	15,450	77,000	28,400	124,000	16,100	16,800	64,400
Capital Charges ($/yr)	54,400	129,000	74,400	81,600	70,100	89,200	276,000
Net Annualized Costs ($/yr)	69,900	206,000	102,800	205,600	86,200	106,000	340,400
Controlled Emissions (1000 Kg/yr)	121.8	121.8	128.5	128.5	134.3	136.1	133.1
Cost per Kg Controlled ($/Kg)	0.57	1.69	0.80	1.60	0.64	0.78	2.56

(1) Capital cost of $117,000 and direct operating cost of $13,000 - Reference 1, Section 4.

(2) Capital cost of $159,000 and direct operating cost of $108,000 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

TABLE B-4. SUMMARY OF CONTROL COSTS FOR 18.2 megagram/hour MODEL PLANT PRODUCING GRAY IRON (TWO-FURNACE SHOP)

Evacuation System	Side Draft Only	Side Draft Only	Side Draft Only	Side Draft Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Side Draft
Process Constraint	--	--	Clean Scrap	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Pre-Heater(1)	Briquetter(2)	--	--	--
Pollutant Removal Efficiency %	87	87	92	92	96	97.5	95
Model New Facilities							
Installed Capital ($)	587,000	1,003,000	821,000	905,000	698,000	830,000	1,620,000
Direct Operating Cost ($/yr)	29,000	139,000	54,000	246,000	30,100	31,400	91,200
Capital Charges ($/yr)	101,000	172,000	141,000	155,000	120,000	142,000	278,000
Net Annualized Costs ($/yr)	130,000	311,000	195,000	401,000	150,100	173,400	369,200
Controlled Emissions (1000 Kg/yr)	243.6	243.6	257.0	257.0	268.6	272.2	266.2
Cost Per Kg Controlled ($/Kg)	0.54	1.28	0.76	1.56	0.56	0.64	1.39
Model Existing Facilities							
Installed Capital ($)	587,000	1,103,000	821,000	905,000	768,000	960,000	2,160,000
Direct Operating Costs ($/yr)	29,000	139,000	54,000	246,000	30,100	31,400	91,200
Capital Charges ($/yr)	101,000	189,000	141,000	155,000	132,000	165,000	370,000
Net Annualized Costs ($/yr)	130,000	328,000	195,000	401,000	162,000	196,400	461,200
Controlled Emissions (1000 Kg/yr)	243.6	243.6	257.0	257.0	268.6	272.2	266.2
Cost per Kg Controlled ($/Kg)	0.54	1.35	0.76	1.56	0.60	0.72	1.73

(1) Capital cost of $243,000 and a direct operating cost of $26,000 - Reference 1, Section 4.

(2) Capital cost of $318,000 and a direct operating cost of $217,000 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

TABLE B-5. SUMMARY OF CONTROL COSTS FOR 22.7 megagram/hour MODEL PLANT PRODUCING GRAY IRON (SINGLE-FURNACE SHOP)

Evacuation System	Side Draft Only	Side Draft Only	Side Draft Only	Side Draft Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Side Draft
Process Constraint	--	--	Clean Scrap	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse Pre-Heater(1)	Baghouse Briquetter(2)	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--			--	--	--
Pollutant Removal Efficiency %	87	87	92	92	96	97.5	95
Model New Facilities							
Installed Capital ($)	710,000	1,140,000	949,000	1,028,000	845,000	1,000,000	1,650,000
Direct Operating Cost ($/yr)	45,500	223,000	91,200	306,500	47,000	48,400	115,000
Capital Charges ($/yr)	122,000	196,000	163,000	176,000	145,000	172,000	283,000
Net Annualized Costs ($/yr)	167,500	419,000	254,200	482,500	192,000	220,400	398,600
Controlled Emissions (1000 Kg/yr)	440.0	440.0	468.4	468.4	489.7	496.2	485.2
Cost Per Kg Controlled ($/Kg)	0.38	0.95	0.54	1.03	0.39	0.44	0.82
Model Existing Facilities							
Installed Capital ($)	710,000	1,260,000	949,000	1,028,000	933,000	1,080,000	2,300,000
Direct Operating Costs ($/yr)	45,500	223,000	91,200	306,500	47,000	48,400	115,600
Capital Charges ($/yr)	122,000	216,000	163,000	176,000	160,000	185,000	394,000
Net Annualized Costs ($/yr)	167,500	439,000	254,200	482,000	207,000	233,400	509,600
Controlled Emissions (1000 Kg/yr)	440.0	440.0	468.4	468.4	489.7	496.2	485.2
Cost per Kg Controlled ($/Kg)	0.38	1.00	0.54	1.03	0.42	0.47	1.05

(1) Capital cost of $239,000 and direct operating costs of $45,700 - Reference 1, Section 4.

(2) Capital cost of $318,000 and direct operating costs of $261,000 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

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TABLE B-6. SUMMARY OF CONTROL COSTS FOR 45.4 megagram/hour MODEL PLANT PRODUCING GRAY IRON (TWO-FURNACE SHOP)

Evacuation System	Side Draft Only	Side Draft Only	Side Draft Only	Side Draft Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Side Draft
Process Constraint	--	--	Clean Scrap	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Pre-Heater[(1)]	Briquetter[(2)]	--	--	--
Pollutant Removal Efficiency %	87	87	92	92	96	97.5	95
Model New Facilities							
Installed Capital ($)	1,293,000	1,660,000	1,770,000	1,930,000	1,540,000	1,830,000	2,650,000
Direct Operating Cost ($/yr)	89,000	418,000	180,000	611,000	91,500	94,400	201,000
Capital Charges ($/yr)	222,000	285,000	304,000	331,000	264,000	314,000	454,000
Net Annualized Costs ($/yr)	311,000	703,000	484,000	942,000	355,500	408,400	655,000
Controlled Emissions (1000 Kg/yr)	880.0	880.0	936.8	936.8	979.4	992.4	970.4
Cost Per Kg Controlled ($/Kg)	0.35	0.80	0.52	1.00	0.36	0.41	0.67
Model Existing Facilities							
Installed Capital ($)	1,293,000	1,800,000	1,770,000	1,930,000	1,690,000	2,120,000	3,530,000
Direct Operating Costs ($/yr)	89,000	418,000	180,000	611,000	91,500	94,400	201,000
Capital Charges ($/yr)	222,000	309,000	304,000	331,000	290,000	364,000	605,000
Net Annualized Costs ($/yr)	311,000	727,000	484,000	942,000	381,500	458,400	806,000
Controlled Emissions (1000 Kg/yr)	880.0	880.0	936.8	936.8	979.4	992.4	970.4
Cost per Kg Controlled ($/Kg)	0.35	0.83	0.52	1.00	0.39	0.46	0.83

(1) Capital cost of $478,000 and a direct operating cost of $91,400 - Reference 1, Section 4.

(2) Capital cost of $636,000 and a direct operating cost of $522,000 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

APPENDIX C

DETAILED COST ANALYSIS FOR FURNACES PRODUCING STEEL CASTINGS

TABLE C-1. SUMMARY OF CONTROL COSTS FOR 3.6 megagram/hour MODEL PLANT PRODUCING STEEL CASTINGS (SINGLE-FURNACE SHOP)

Evacuation System	Side Draft Only	Side Draft Only	Side Draft Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Side Draft
Process Constraint	--	--	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse (1)	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Briquetter	--	--	--
Pollutant Removal Efficiency %	89.5	89.5	93	93	97.5	97
Model New Facilities						
Installed Capital ($)	198,000	538,000	357,000	236,000	280,000	1,104,000
Direct Operating Cost ($/yr)	9,170	49,000	32,300	9,500	10,000	56,800
Capital Charges ($/yr)	33,400	92,300	61,200	40,400	48,000	189,000
Net Annualized Costs ($/yr)	42,570	141,300	93,500	49,400	58,000	245,800
Controlled Emissions (1000 Kg/yr)	41.66	41.66	43.25	43.25	45.36	45.15
Cost per Kg Controlled ($/Kg	1.02	3.39	2.16	1.14	1.28	5.44
Model Existing Facilities						
Installed Capital ($)	198,000	592,000	357,000	260,000	325,000	1,470,000
Direct Operating Costs ($/yr)	9,170	49,000	32,300	9,500	10,000	56,800
Capital Charges ($/yr)	33,400	102,000	61,200	44,600	55,700	252,000
Net Annualized Costs ($/yr)	42,570	151,000	93,500	54,100	65,700	308,800
Controlled Emissions (1000 kg/yr)	41.66	41.66	43.25	43.25	45.36	45.15
Cost per Kg Controlled ($/Kg)	1.02	3.62	2.16	1.25	1.45	6.84

(1) Capital cost of $159,000 and direct operating cost of $23,100 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

TABLE C-2. SUMMARY OF CONTROL COSTS FOR 7.3 megagram/hour MODEL PLANT PRODUCING STEEL CASTINGS (TWO FURNACE SHOP)

Evacuation System	Side Draft Only	Side Draft Only	Side Draft Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Side Draft
Process Constraint	--	--	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Briquetter[1]	--	--	--
Pollutant Removal Efficiency %	89.5	89.5	93	93	97.5	97
Model New Facilities						
Installed Capital ($)	400,000	790,000	559,000	476,000	570,000	1,300,000
Direct Operating Cost ($/yr)	19,800	85,700	66,000	20,600	21,500	64,800
Capital Charges ($/yr)	68,600	135,000	95,900	81,600	97,800	223,000
Net Annualized Costs ($/yr)	88,400	220,700	162,000	102,000	119,300	287,800
Controlled Emissions (1000 Kg/yr)	83.3	83.3	86.5	86.5	90.7	90.3
Cost per Kg Controlled ($/Kg	1.06	2.65	1.87	1.18	1.32	3.19
Model Existing Facilities						
Installed Capital ($)	400,000	870,000	559,000	524,000	660,000	1,800,000
Direct Operating Costs ($/yr)	19,800	85,700	66,000	20,600	21,500	64,800
Capital Charges ($/yr)	68,600	149,000	95,900	89,900	113,000	308,700
Net Annualized Costs ($/yr)	88,400	234,700	162,000	110,500	134,500	373,500
Controlled Emissions (1000 kg/yr)	83.3	83.3	86.5	86.5	90.7	90.3
Cost per Kg Controlled ($/Kg)	1.06	2.82	1.87	1.28	1.48	4.14

(1) Capital cost of $159,000 and direct operating cost of $46,200 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

TABLE C-3. SUMMARY OF CONTROL COSTS FOR 9.1 megagram/hour MODEL PLANT PRODUCING STEEL CASTINGS (SINGLE-FURNACE SHOP)

Evacuation System	Direct Evac. Only	Direct Evac. Only	Direct Evac. Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Direct Evac.
Process Constraint	--	--	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Briquetter[1]	--	--	--
Pollutant Removal Efficiency %	89.5	89.5	93	93	97.5	97
Model New Facilities						
Installed Capital ($)	127,500	382,000	287,000	370,000	448,000	1,210,000
Direct Operating Cost ($/yr)	5,950	33,500	114,500	16,100	16,800	64,800
Capital Charges ($/yr)	21,900	65,500	49,200	63,400	76,800	233,000
Net Annualized Costs ($/yr)	27,850	99,000	163,700	79,500	93,600	287,800
Controlled Emissions (1000 Kg/yr)	125.0	125.0	129.7	129.7	136.1	135.4
Cost per Kg Controlled ($/Kg	0.22	0.79	1.26	0.61	0.69	2.13
Model Existing Facilities						
Installed Capital ($)	127,500	420,000	287,000	409,000	520,000	1,610,000
Direct Operating Costs ($/yr)	5,950	33,500	114,500	16,100	16,800	64,800
Capital Charges ($/yr)	21,900	72,000	48,200	70,100	89,200	309,000
Net Annualized Costs ($/yr)	27,850	105,500	163,700	86,200	106,000	374,000
Controlled Emissions (1000 kg/yr)	125.0	125.0	129.7	129.7	136.1	135.4
Cost per Kg Controlled ($/Kg)	0.22	0.84	1.26	0.66	0.78	2.76

(1) Capital cost of $139,000 and direct operating cost of $108,000 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

TABLE C-4. SUMMARY OF CONTROL COSTS FOR 18.2 megagram/hour MODEL PLANT PRODUCING STEEL CASTINGS (TWO-FURNACE SHOP)

Evacuation System	Direct Evac. Only	Direct Evac. Only	Direct Evac. Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Direct Evac.
Process Constraint	--	--	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Briquetter[1]	--	--	--
Pollutant Removal Efficiency %	89.5	89.5	93	93	97.5	97
Model New Facilities						
Installed Capital ($)	236,000	559,000	554,000	698,000	830,000	1,362,000
Direct Operating Cost ($/yr)	11,900	58,000	228,900	30,100	31,400	74,400
Capital Charges ($/yr)	40,500	95,900	95,000	120,000	142,000	234,000
Net Annualized Costs ($/yr)	52,400	153,900	323,900	150,100	173,400	308,400
Controlled Emissions (1000 Kg/yr)	250.0	250.0	259.4	259.4	272.2	270.8
Cost per Kg Controlled ($/Kg	0.21	0.62	1.25	0.58	0.64	1.14
Model Existing Facilities						
Installed Capital ($)	236,000	615,000	554,000	768,000	960,000	1,820,000
Direct Operating Costs ($/yr)	11,900	58,000	228,900	30,000	31,400	74,400
Capital Charges ($/yr)	40,500	105,000	95,000	132,000	165,000	312,000
Net Annualized Costs ($/yr)	52,400	163,000	323,900	162,000	196,400	386,000
Controlled Emissions (1000 kg/yr)	250.0	250.0	259.4	259.4	272.2	270.8
Cost per Kg Controlled ($/Kg)	0.21	0.65	1.25	0.62	0.72	1.43

[1] Capital cost of $318,000 and direct operating cost of $217,000 - Reference 6. Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

TABLE C-5. SUMMARY OF CONTROL COSTS FOR 22.7 megagram/hour MODEL PLANT PRODUCING STEEL CASTINGS (SINGLE-FURNACE SHOP)

Evacuation System	Direct Evac. Only	Direct Evac. Only	Direct Evac. Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Direct Evac.
Process Constraint	--	--	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Briquetter[1]	--	--	--
Pollutant Removal Efficiency %	89.5	89.5	93	93	97.5	97
Model New Facilities						
Installed Capital ($)	236,000	608,000	554,000	845,000	1,000,000	1,650,000
Direct Operating Cost ($/yr)	15,800	83,700	276,800	47,000	48,400	115,600
Capital Charges ($/yr)	45,100	104,300	95,000	145,000	172,000	283,000
Net Annualized Costs ($/yr)	60,900	188,000	371,800	192,000	220,400	398,600
Controlled Emissions (1000 Kg/yr)	455.6	455.6	473.0	473.0	496.2	493.8
Cost per Kg Controlled ($/Kg	0.14	0.42	0.78	0.41	0.44	0.81
Model Existing Facilities						
Installed Capital ($)	236,000	669,100	554,000	933,000	1,080,000	2,300,000
Direct Operating Costs ($/yr)	15,800	83,700	276,800	47,000	48,400	115,600
Capital Charges ($/yr)	45,100	114,700	95,000	160,000	185,000	394,000
Net Annualized Costs ($/yr)	60,900	198,400	371,800	207,000	233,400	509,600
Controlled Emissions (1000 kg/yr)	455.6	455.6	473.0	473.0	496.2	493.8
Cost per Kg Controlled ($/Kg)	0.14	0.44	0.78	0.44	0.47	1.04

(1) Capital cost of $318,000 and direct operating cost of $261,000 - Reference 5, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.

TABLE C-6. SUMMARY OF CONTROL COSTS FOR 45.4 megagram/hour MODEL PLANT PRODUCING STEEL CASTINGS (TWO-FURNACE SHOP)

Evacuation System	Direct Evac. Only	Direct Evac. Only	Direct Evac. Only	Close Capture System	Close Capture System + Ladle Enclosure	Canopy and Direct Evac.
Process Constraint	--	--	Clean Scrap	--	--	--
Control Device	Baghouse	Scrubber	Baghouse	Baghouse	Baghouse	Baghouse
Auxiliary Equipment	--	--	Briquetter[(1)]	--	--	--
Pollutant Removal Efficiency %	89.5	89.5	93	93	97.5	97
Model New Facilities						
Installed Capital ($)	494,000	890,000	1,130,000	1,540,000	1,830,000	1,984,000
Direct Operating Cost ($/yr)	30,700	153,000	553,000	91,500	94,400	143,000
Capital Charges ($/yr)	84,700	153,000	194,000	264,000	314,000	340,000
Net Annualized Costs ($/yr)	115,400	306,000	747,000	355,500	408,400	483,000
Controlled Emissions (1000 Kg/yr)	911.2	911.2	946.0	946.0	992.4	987.6
Cost per Kg Controlled ($/Kg	0.13	0.34	0.79	0.38	0.41	0.49
Model Existing Facilities						
Installed Capital ($)	494,000	980,000	1,130,000	1,690,000	2,120,000	2,640,000
Direct Operating Costs ($/yr)	30,700	153,000	553,000	91,500	94,400	143,000
Capital Charges ($/yr)	84,700	168,000	194,000	290,000	364,000	453,000
Net Annualized Costs ($/yr)	115,400	321,000	747,000	381,500	458,400	596,000
Controlled Emissions (1000 kg/yr)	911.2	911.2	946.0	946.0	992.4	987.6
Cost per Kg Controlled ($/Kg)	0.13	0.35	0.79	0.40	0.46	0.60

(1) Capital cost of $636,000 and direct operating cost of $522,000 - Reference 6, Section 4.

SOURCE OF BASIC COST INFORMATION: Reference 3, Section 4.